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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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INVESTIGATION BY THE TRANSONIC-BUMP METHOD OF A 35° SWEPTBACK SEMISPAN MODEL EQUIPPED WITH A FLAP OPERATED BY A SERIES OF SERVOVANES LOCATED AHEAD OF AND GEARED TO THE FLAP

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INVESTIGATION BY THE TRANSONIC-BUMP METHOD OF A 35° SWEPTBACK SEMISPAN MODEL EQUIPPED WITH A FLAP OPERATED BY A SERIES OF SERVOVANES LOCATED AHEAD OF AND GEARED TO THE FLAP[1]

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SUMMARY

An investigation was made in the Langley high-speed 7- by 10-foot tunnel to determine the feasibility of using a servovane control at high-subsonic and low-transonic speeds. This servovane control could presumedly be deflected with relatively low control forces compared to flap-type controls. The control was tested on an untapered semispan wing of aspect ratio 3.04 with 35° of sweepback and a modified NACA 66-009 airfoil section perpendicular to the leading edge.

Throughout the speed range tested (Mach numbers from 0.6 to 1.0) increments of lift, pitching moment, and rolling moment were produced in the correct direction over most of the angle-of-attack range tested. At an angle of attack of 0° the servovane control gave a higher incremental lift coefficient and had a more forward location of center of pressure of lift than a comparable flap-type control. The servovane control tested was subject to rather severe vibrations.

INTRODUCTION

Hydraulic or electrical control boosters are ordinarily used in military airplanes designed to fly at transonic or supersonic speeds because the hinge moments required on the control surfaces far exceed the strength of the pilot. The use of such control boosters is undesirable, however, because of their weight, mechanical complexity, and lack of reliability as compared with conventional aerodynamically balanced control systems. A type of servocontrol has therefore been devised in an effort to obtain a large part of the control operating force aerodynamically and still maintain control effectiveness throughout the speed range.

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[1]Supersedes recently declassified NACA Research Memorandum L51J10 by William H. Phillips and Robert F. Thompson, 1951.

The method of operation of the proposed control system (called a servovane control) is illustrated in figure 1. Figure 1(a) shows the control in neutral. As shown in figure 1(b), movement of the control stick causes a vane, which may be operated with a relatively small control force, to project from the surface of the wing. Drag force on the vane then causes it to rotate about an axis parallel to the control-surface hinge line. This rotation causes rotation of the control surface so that when the vane blows back the control surface deflects in the same direction as the projection of the vane, as illustrated in figure 1(c). Because the action of the vanes in deflecting the flap is that of a servocontrol, this control system will be called a "servovane" control.

In the proposed servovane control system the control stick may be connected directly to the vane with no connection to the flap. Alternatively, the vane may be operated by the control stick in conjunction with a follow-up linkage from the flap in a manner similar to the usual servotab system. Centering springs on the vane may also be added to give the same action as the usual spring-tab control system.

The control force required to operate the servovane control would only be that required to deflect the vanes. In addition to the control effectiveness produced by deflection of the flap as a result of drag forces on the vanes, three effects may serve to increase the control effectiveness. First, the vane should act as a spoiler and provide by itself an increment of lift in the desired direction. This action is unlike that of the conventional servotab because the tab gives lift in the direction opposite from that desired. Second, the reduced pressure behind the vane should assist the vane in deflecting the control surface. Third, this reduced pressure behind the vane should aid in preventing separation of flow on the suction side of the flap.

Wind-tunnel tests of a model of the proposed servovane control system have been made in the Langley high-speed 7- by 10-foot tunnel through a Mach number range from 0.6 to 1.0 using the transonic-bump technique. The model was an untapered semispan wing of aspect ratio 3.04, with 35° sweepback and a modified NACA 66-009 airfoil section perpendicular to the leading edge. The model had a $0.9\frac{b}{2}$-span 0.25-chord flap operated by the servovanes. Measurements of lift, drag, pitching moment, rolling moment, and yawing moment were made through an angle-of-attack range of $\pm 20^\circ$. Control operating forces were not measured. These tests should be regarded as preliminary inasmuch as mechanical difficulties associated with the small size of the model prevented very accurate results from being obtained. The results of these tests are presented, however, to encourage further investigation of controls of this type.

COEFFICIENTS AND SYMBOLS

The forces and moments measured on the model are presented about the wind axes which for the conditions of these tests (zero yaw) correspond to the stability axes if the model is considered as a semispan wing. The pitching-moment data are presented about the point at the plane of symmetry which corresponds to the 30-percent-chord station of the mean aerodynamic chord.

C_L	lift coefficient (Twice lift of semispan model/qS)
C_D	drag coefficient (Twice drag of semispan model/qS)
C_m	pitching-moment coefficient referred to $0.30\bar{c}$ (Twice pitching moment of semispan model/$qS\bar{c}$)
C_n	yawing-moment coefficient (N/qSb)
C_l	rolling-moment coefficient (L/qSb)
N	yawing moment resulting from control deflection, foot-pounds
L	rolling moment resulting from control deflection, foot-pounds
q	free-stream dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
S	twice area of semispan model, 0.219 square foot
b	twice span of semispan model, 0.815 foot
$\bar{c}$	wing mean aerodynamic chord, 0.273 foot
c	local wing chord, feet
c_a	flap chord aft of and measured perpendicular to hinge line, feet
ρ	mass density of air, slugs per cubic foot
V	average air velocity over span of model, feet per second

M effective Mach number over span of model $\left(\frac{2}{S}\int_0^{b/2} cM_a\,dy\right)$

M_a average chordwise local Mach number

M_l local Mach number

y spanwise distance from plane of symmetry

A aspect ratio $\left(b^2/S\right)$

R Reynolds number of wing based on $\bar{c}$

λ taper ratio (Tip chord/Root chord)

Λ angle of sweepback

α angle of attack of wing relative to air stream, degrees

δ_v vane angle, measured between the edge of vane and wing surface with the vane perpendicular to the wing chord plane (positive when deflected from lower surface, see fig. 4), degrees

δ_f flap deflection relative to wing chord plane, measured perpendicular to aileron hinge axis (positive when trailing edge is down), degrees

ΔC_L increment of lift coefficient due to an increase in flap deflection from 0° to 10°

$$C_{L_{\delta_v}} = \left(\frac{\partial C_L}{\partial \delta_v}\right)_\alpha$$

$$C_{m_{\delta_v}} = \left(\frac{\partial C_m}{\partial \delta_v}\right)_\alpha$$

$$C_{l_{\delta_v}} = \left(\frac{\partial C_l}{\partial \delta_v}\right)_\alpha$$

The subscript outside the parenthesis indicates that α was held constant.

MODEL AND APPARATUS

A drawing of the semispan model tested is given in figure 2 and a photograph of the model is shown as figure 3. The model had an aspect ratio of 3.04 (based on full-span dimensions), a taper ratio of 1, a sweepback of 35°, and a modified NACA 66-009 airfoil section normal to the leading edge. The airfoil section was modified with a straight-line fairing from the 0.65-chord station to the trailing edge. The fixed part of the model was constructed of duralumin. A thin circular end plate having a diameter approximately equal to the model chord was fastened to the root of the model.

The servovane control consisted of a set of four vanes located in a torque rod at the 0.62-chord station. The rod was geared to a 0.25-chord flap through a pair of spur gears such that the ratio of rod rotation to flap rotation was 2 to 1. The flap, which extended over the inboard 0.9 of the semispan, was constructed with a steel spar and balsa wood inserts behind the hinge line. The flap had a 0.2-flap-chord overhang balance and was completely mass-balanced.

Because of the small size of the model, the vanes were not made moveable as they would be in an actual installation. Instead, the vanes were tested at a series of fixed deflections simulating rotation of the vanes about pivots located as shown in figure 4.

The semispan model was mounted vertically on a five-component electrical strain-gage balance. The balance was mounted in a chamber within the bump and the chamber was sealed except for a rectangular hole through which the wing mounting butt and control gearing arrangement passed. This hole was covered by the circular end plate which was approximately 1/16 inch above the bump surface. Aerodynamic forces and moments were measured with a calibrated potentiometer and the flap angle was measured by means of a slide-wire position indicator (see fig. 3) attached to the flap hinge rod within the bump chamber.

TESTS

Tests were made in the Langley high-speed 7- by 10-foot tunnel by the transonic-bump technique (reference 1). The tests covered a range of Mach numbers from 0.6 to 1.0. Typical contours of local Mach number in the vicinity of the model location on the bump, obtained from surveys with no model in position, are shown in figure 5. The long-dashed lines shown near the root of the wing in figure 5 indicate a local Mach number

5 percent below the maximum value and represent the extent of the bump boundary layer. The effective test Mach number was obtained from contour charts similar to those in figure 5 by use of the relationship

$$M = \frac{2}{S}\int_0^{b/2} cM_a \, dy$$

The variation of Reynolds number with Mach number for average test conditions is presented in figure 6. Reynolds number is based on the wing mean aerodynamic chord (0.273 ft). During the tests the servovane control was left free to float. Force and moment data and flap angle were obtained through an angle-of-attack range of $\pm 20^\circ$ with fixed vane deflections of 0°, 2°, 4°, 6°, and 12°. Vane angle plotted against maximum vane projection in percent streamwise chord is presented in figure 4. Deflections greater than 12° were not tested since the vane at 12° deflection caused the torque rod to rotate until the projected vanes were close to the vane stops (see fig. 2). At $\delta_v = 0^\circ$ the torque-rod rotation was not limited by the vane stops.

To facilitate testing it was necessary to complete the runs through the range of angles of attack and Mach numbers with a given vane deflection before proceeding to the next vane deflection. During this time the vane-flap combination vibrated rather severely which resulted in wear of the gears and bearings in the flap-operation mechanism. The gears had to be replaced several times during the tests in order to avoid excessive backlash. For this reason, some doubt exists as to the accuracy of the increments in the measured quantities at the successive values of vane deflection. The tests cannot therefore be relied on very strongly in establishing the degree of linearity of the control.

CORRECTIONS

No corrections have been applied to the data for the chordwise and spanwise velocity gradients or for the forces on the end plate. Corrections were not applied for model distortion due to air loads because this effect has been shown to be small on a similar model (reference 2).

No reflection-plane corrections have been applied to the rolling-moment data. The lift and pitching-moment data represent the aerodynamic effects of deflection in the same direction of the control surfaces on both semispans of the complete wing.

RESULTS AND DISCUSSION

The variations of flap deflection and lift coefficient for various Mach numbers at a series of values of vane deflection are plotted as functions of angle of attack in figure 7. Corresponding values for the drag coefficient and pitching-moment coefficient are given in figure 8 and for the yawing-moment coefficient and rolling-moment coefficient in figure 9. These data indicate that when the vanes were projected from the lower surface of the wing (the condition tested) the servovane control in the angle-of-attack range from near the negative stall to beyond the positive stall (20°) produced increments of lift, pitching moment, and rolling moment in the correct direction through the speed range to a Mach number of 1.0. At $M = 1.0$ there appears to be a control reversal at high positive angles of attack and low vane projections. This reversal was generally eliminated by an increase in vane projection. The effectiveness of the control was reduced at the higher negative angles of attack, becoming about zero when the stall was reached. Beyond the stall at negative angles of attack, control reversal occurred in all cases except at $M = 1.0$. The increments in lift, produced with increasing vane deflection, indicate the degree of linearity of the control. Except for the reversal conditions mentioned previously, there was no apparent dead spot in the action of the control at the small vane deflections inasmuch as the smallest deflection tested (2°) produced an appreciable lift increment throughout the Mach number range. Some nonlinearity in the action of the control appeared to exist at larger deflections.

Cross plots showing the variation of flap deflection with vane angle at zero angle of attack are given in figure 10. The corresponding variations of lift coefficient, pitching-moment coefficient, and rolling-moment coefficient with vane deflection are given in figure 11. These curves have been plotted from the individual test points at an angle of attack of 0° rather than from the faired curves. No test data were obtained for $\delta_v = 4^\circ$ at $M = 1.0$. The data of figure 10 indicate a nonlinear variation of flap deflection with vane angle between vane angles of 2° and 6° at the lowest Mach numbers tested, but this nonlinearity tends to disappear at the higher Mach numbers. The variations of the aerodynamic forces with vane deflection shown in figure 11 appear to be somewhat more linear than the variations of flap angle. This indicates that the spoiler action of the vanes tend to linearize the over-all control results.

Examination of the data of figure 11 shows that the control retained most of its effectiveness in producing lift, pitching moment, and rolling moment throughout the Mach number range tested. Average slopes taken from the curves of figure 11 through a vane-deflection range of 0° up to 6° are given in figure 12 to indicate the approximate variation of effectiveness with Mach number. These results show that the lift effectiveness increased slightly up to $M = 0.92$ and decreased beyond this point. The effectiveness of the control in producing rolling moment showed a similar trend, but the decrease in effectiveness beyond $M = 0.9$ was of smaller magnitude. The effectiveness of the control in producing pitching moment increased with increasing Mach number between 0.6 and 1.0.

Although the results given in figure 12 show the variation of control effectiveness with Mach number, they do not allow a comparison of the effectiveness of the servovane control with that of a conventional flap-type control. In order to make such a comparison, the incremental lift coefficient at $\alpha = 0^\circ$ due to a vane deflection resulting in 10° flap deflection for the servovane control is compared in figure 13 with incremental lift coefficient due to a conventional flap-type control deflected 10°. The flap-type control used for comparison was a one-quarter-chord full-span flap having a 31-percent-flap-chord overhang balance which was tested on a model of the same plan form as that used with the servovane control (reference 3). The flap model differed slightly from the servovane model in that it had an NACA 65-009 airfoil normal to the leading edge. The position of the center of pressure of lift due to control deflection resulting from an increase in flap deflection from 0° to 10° is also presented in figure 13 as a function of Mach number. The servovane control gave a small increase in ΔC_L over that obtained with the flap control up to $M = 0.8$ with the increase becoming fairly large from $M = 0.8$ to $M = 0.95$. A flap deflection of 10° was not obtained for the servovane control at $M = 1.0$.

The position of the center of pressure of lift is considerably forward for the servovane control as compared with the flap. This would be expected because of the spoiler action of the vane. Location of the center of pressure varied from 39 to 42 percent of the mean aerodynamic chord for the servovane control through the speed range and from 60 to 82 percent of the mean aerodynamic chord for the flap control. The more forward position of the center of pressure for the servovane control would result in decreased twisting of the wing and thereby would increase the effectiveness of the control on an actual airplane at high values of indicated airspeed.

As previously mentioned, the gears and bearings of the flap operating mechanism were subject to considerable wear during the course of the

testing as a result of control vibration. Part of this vibration is probably due to tunnel vibration or air-stream turbulence, but the amount of wear encountered seemed to indicate that the control may have had an inherent tendency to vibrate possibly as a result of buffeting of the flap by the unsteady flow from the vanes. No attempt was made in the present investigation to analyze these vibrations, but the possibility of such vibrations should be considered in a practical application of this type of control.

SUGGESTIONS FOR APPLICATION OF SERVOVANE CONTROLS

The servovane control appears promising for transonic airplanes because of the possibility of obtaining improved effectiveness and relatively low control forces as compared to conventional flap-type controls. The control forces required to operate the vanes might still be fairly large, however, in terms of human pilots capabilities unless careful consideration were given in their design to the reduction of operating forces. These forces could be minimized by reducing the span and thickness of the vanes as much as possible. The use of a large number of small vanes would therefore appear desirable. Mass balance of the vanes as well as the flap would probably be required to prevent flutter. The use of short-span vanes would have the further advantages of increasing the ease of obtaining mass balance, reducing the inertia of the vane system, and decreasing the bending of the vanes due to air loads.

As mentioned in the introduction, the servovanes may be connected directly to the control stick with no connection to the control surface, or they may be operated by the control stick in conjunction with a follow-up linkage from the control surface. The arrangement utilizing the follow-up linkage would tend to mask any nonlinear characteristics which might be introduced by the vanes, inasmuch as only a small portion of the stick travel would be required to deflect the vane fully. On the other hand, the follow-up linkage from the control surface might introduce a tendency to flutter if any lag existed between the deflection of the vane and the resulting aerodynamic moments on the control surface. Elimination of the follow-up linkage would also allow a greater mechanical advantage of the control stick over the vanes, which would reduce the control forces in cases where the vane hinge moments might be important. These considerations indicate that for a transonic airplane the use of a direct connection of the vanes to the control stick with no connection to the control surface might be the most suitable arrangement.

CONCLUSIONS

On the basis of wind-tunnel tests of a servovane control on a 35° sweptback untapered airfoil model of aspect ratio 3.04, the following conclusions were reached:

1. Through the Mach number range tested (0.6 to 1.0) the servovane control produced increments of lift, pitching moment, and rolling moment in the correct direction over most of the angle-of-attack range tested. When the vanes were projected from the lower surface of the wing, a reversal of effectiveness occurred beyond the stall at negative angles of attack in all cases except at a Mach number of 1.0.

2. Although results of the present investigation cannot be relied on very strongly in establishing the degree of linearity of the control, no dead spot was apparent for small control deflections from zero deflection.

3. At an angle of attack of 0° and for a vane deflection resulting in a change in flap deflection from 0° to 10° the servovane control appeared to give a greater incremental lift coefficient than a flap-type control. The difference in incremental lift coefficient became rather large at high test Mach numbers.

4. The position of the center of pressure of lift due to control deflection was considerably further forward for the servovane control than for a flap-type control.

5. The control as tested was subject to severe vibrations indicated by the amount of wear encountered in the gears and bearings of the flap operation mechanism.

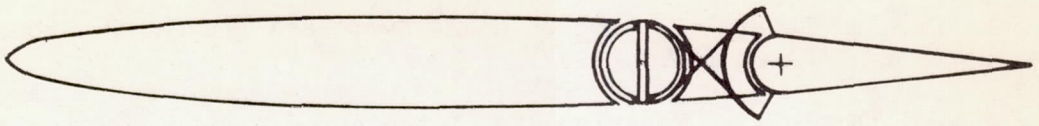
Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 11, 1951.

REFERENCES

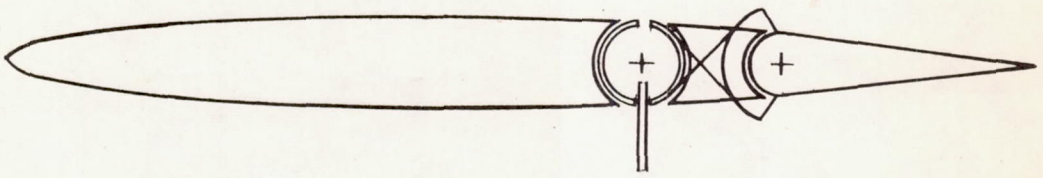
1. Schneiter, Leslie E., and Ziff, Howard L.: Preliminary Investigation of Spoiler Lateral Control on a 42° Sweptback Wing at Transonic Speeds. NACA RM L7F19, 1947.

2. Johnson, Harold I.: Measurements of the Aerodynamic Characteristics of a 35° Sweptback NACA 65-009 Airfoil Model with $\frac{1}{4}$-Chord Plain Flap by the NACA Wing-Flow Method. NACA RM L7F13, 1947.

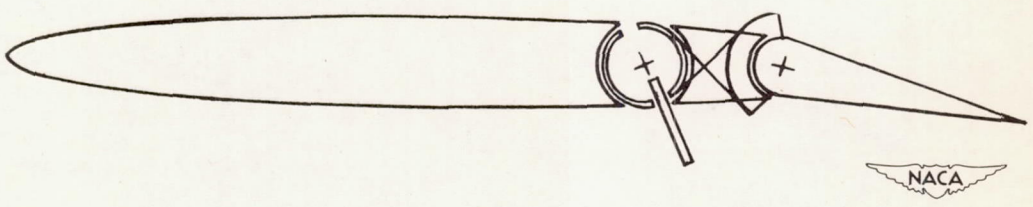
3. Johnson, Harold I., and Goodman, Harold R.: Measurements of Aerodynamic Characteristics of a 35° Sweptback NACA 65-009 Airfoil Model with $\frac{1}{4}$-Chord Flap Having a 31-Percent-Flap-Chord Overhang Balance by the NACA Wing-Flow Method. NACA RM L50H09, 1950.



(a) Servovane control in neutral.



(b) Vane deflected.



(c) Vane and flap deflected.

Figure 1.- Operation of the servovane control.

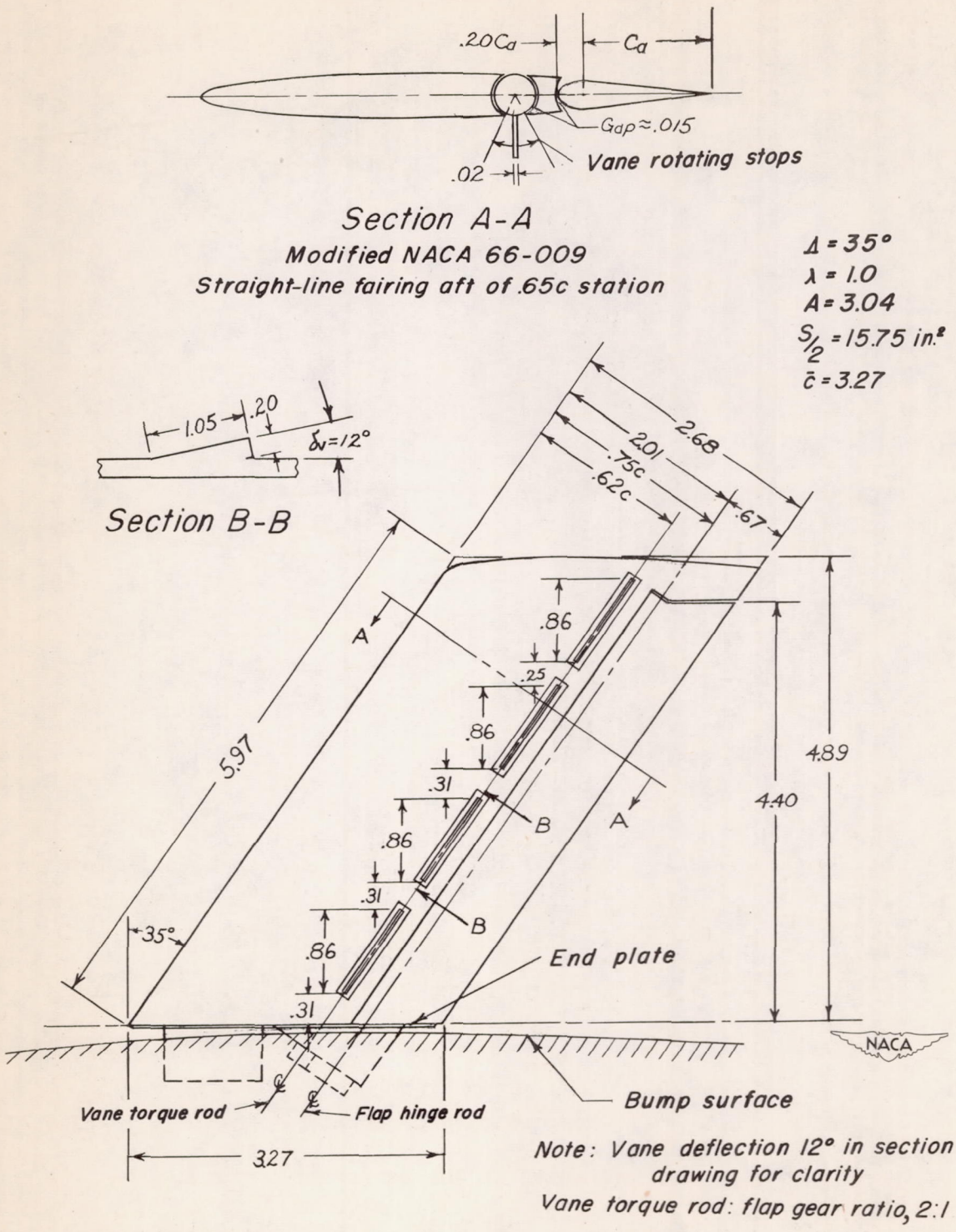


Figure 2.- Plan form and cross section of the left semispan model. (All dimensions are in inches.)

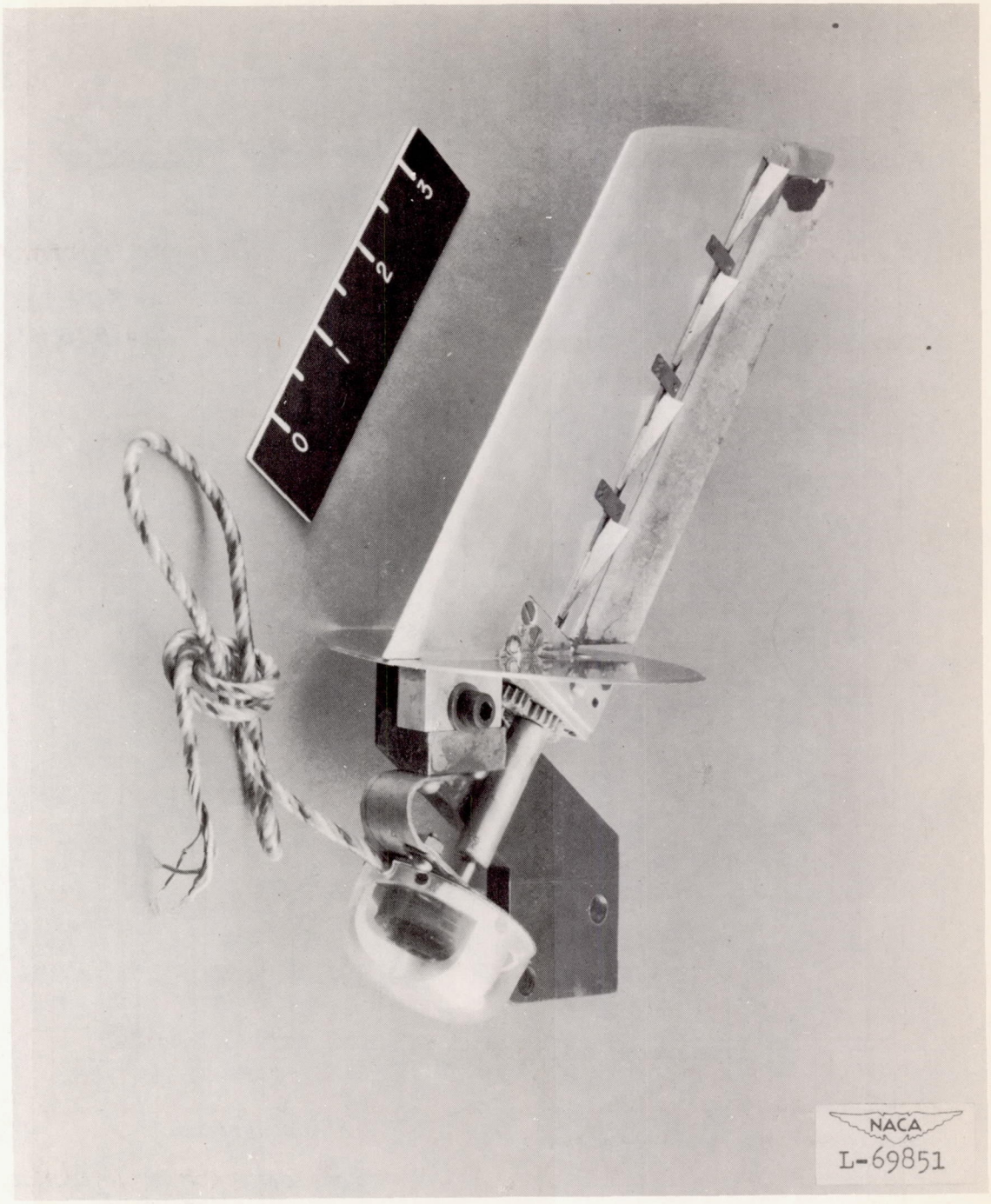
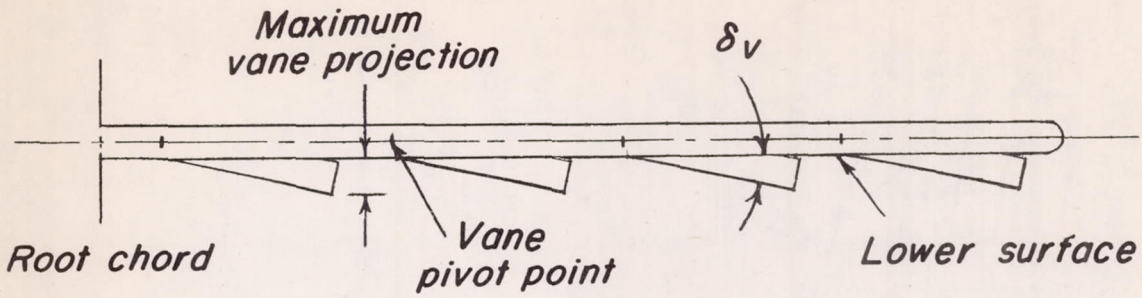


Figure 3.- Photograph of test model. Vanes deflected 12°.



Section through wing parallel to leading edge and forward of vanes ($\delta_V = 12°$)

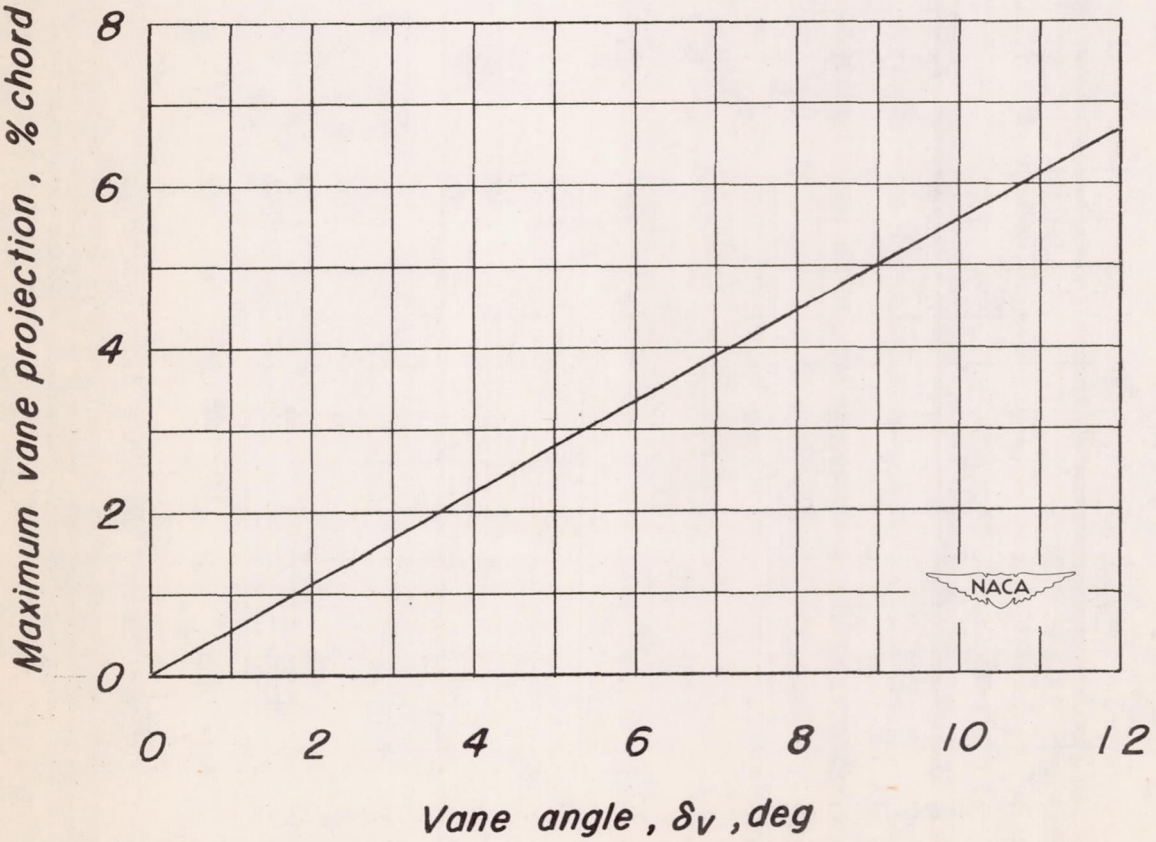


Figure 4.- Vane geometry. (Vanes in vertical position.)

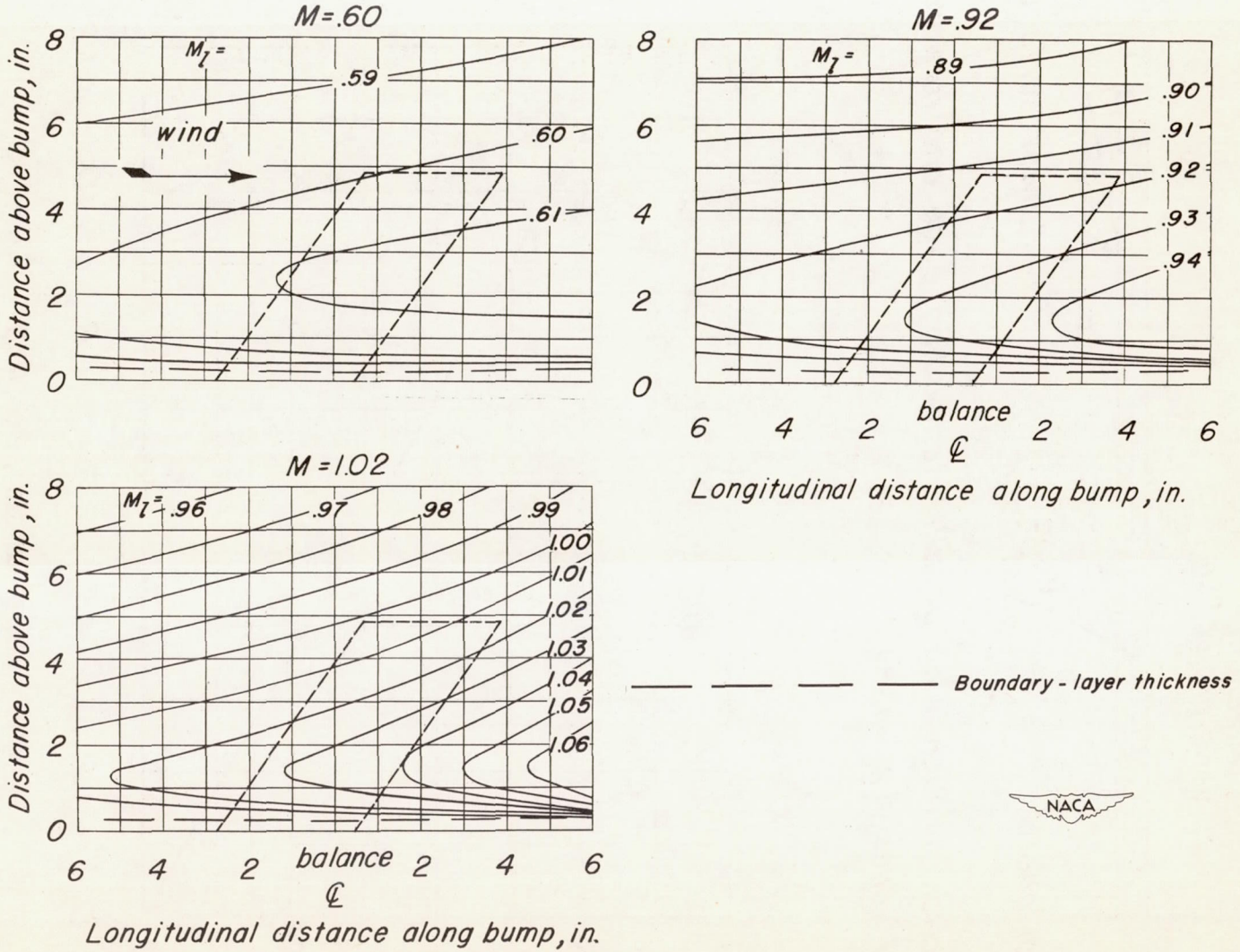


Figure 5.- Typical Mach number contour over transonic bump in region of model location.

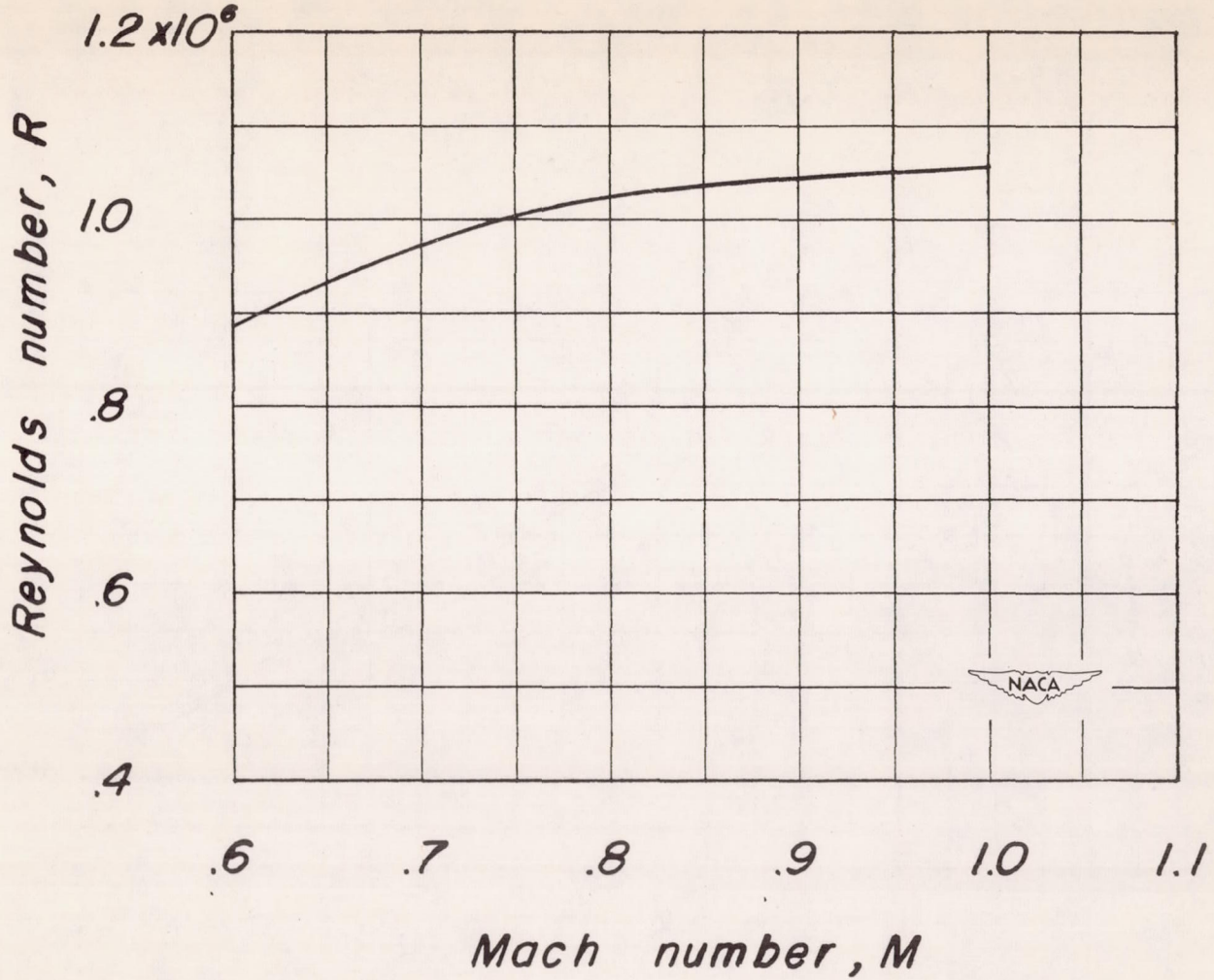
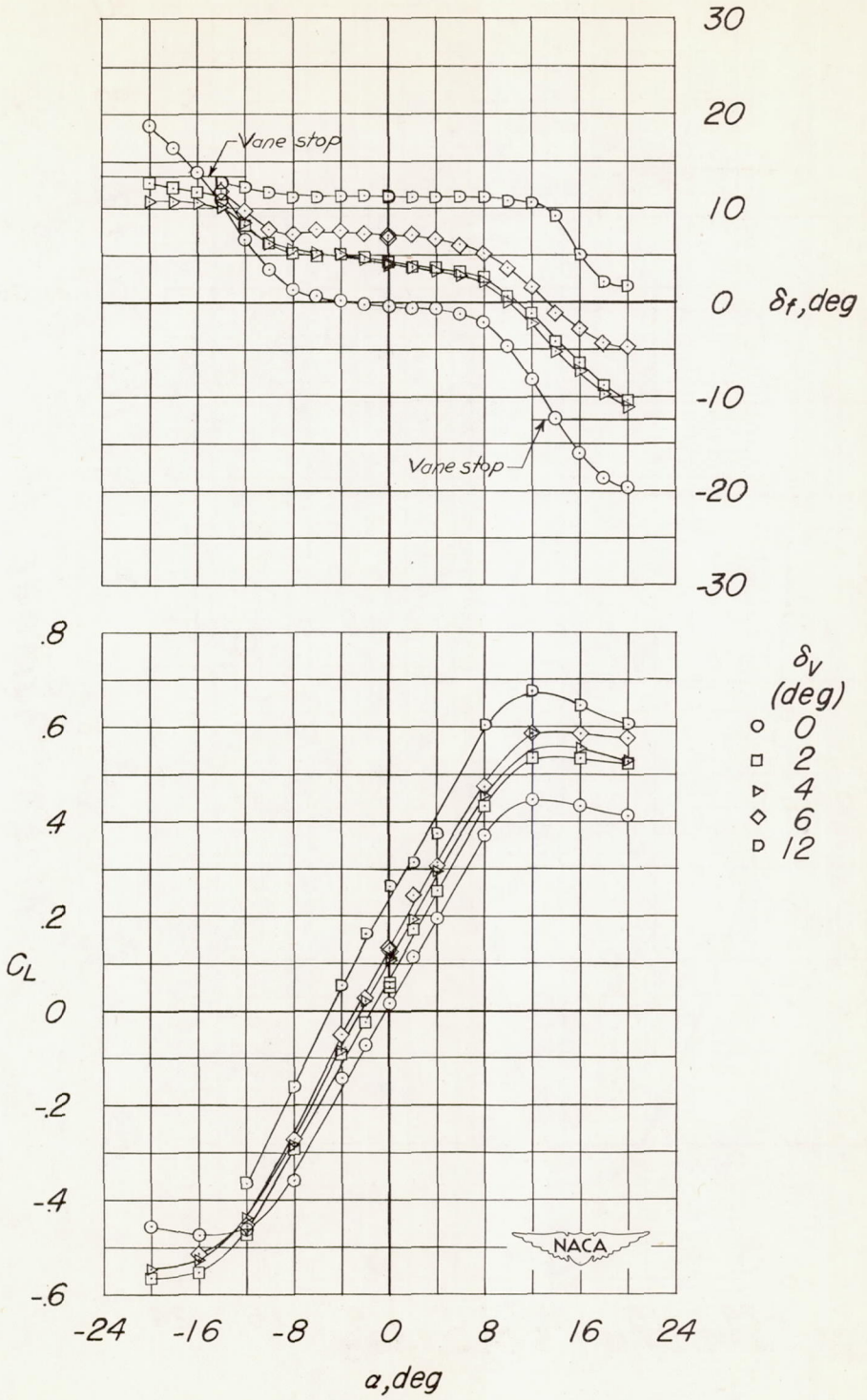
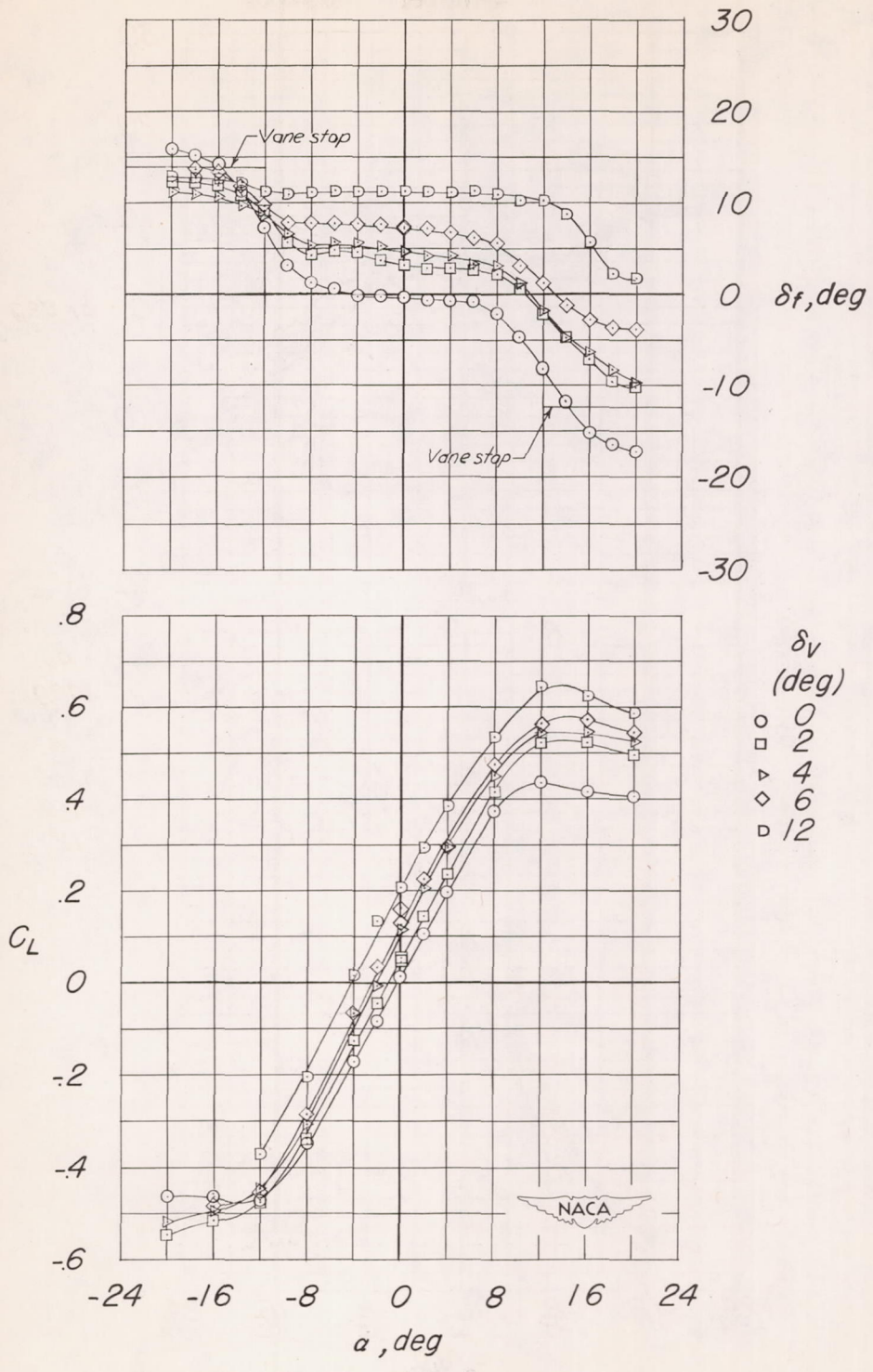


Figure 6.- Variation of average Reynolds number with Mach number.



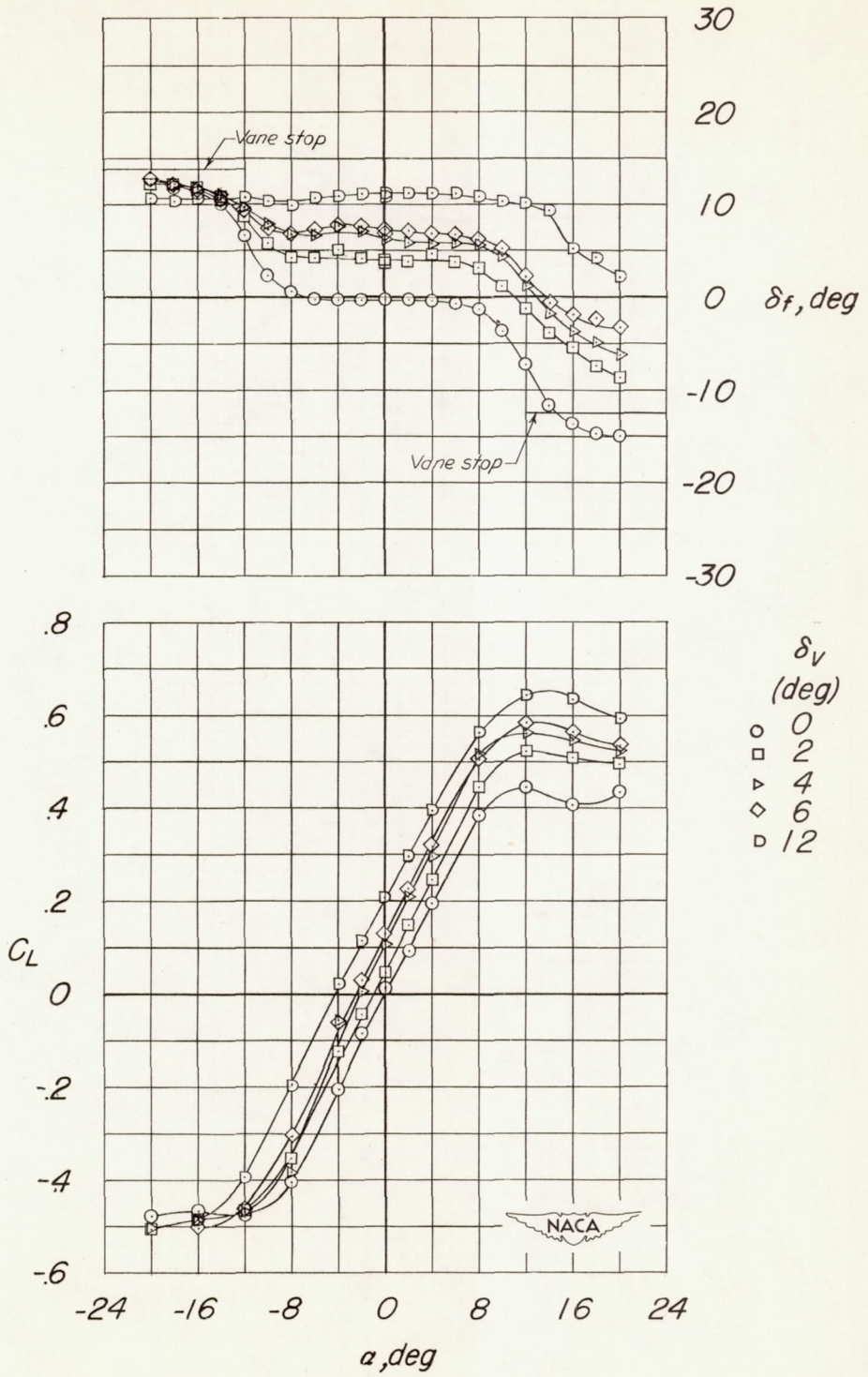
(a) M = 0.60.

Figure 7.- Variation of flap deflection and lift coefficient with angle of attack for various vane angles.



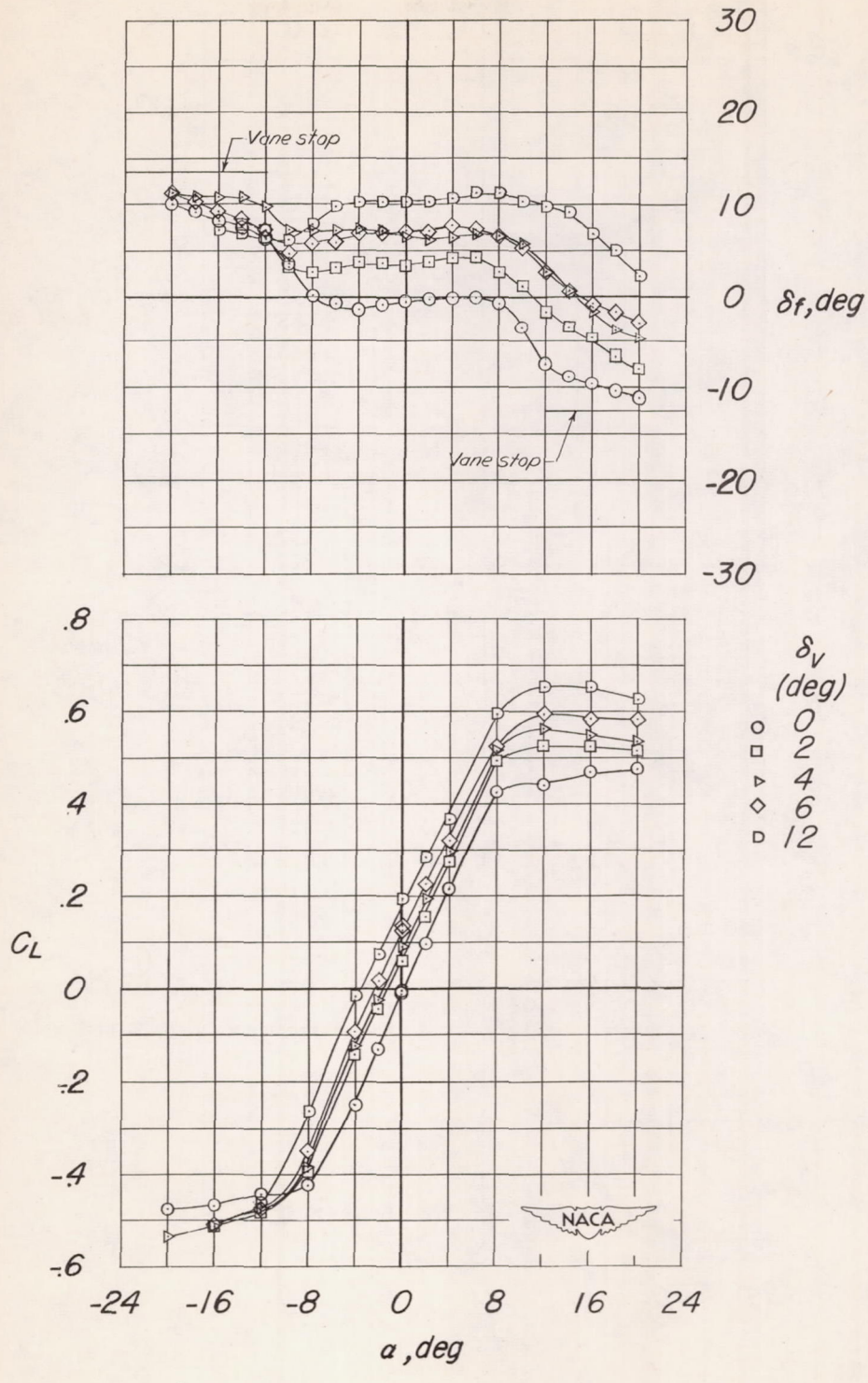
(b) M = 0.70.

Figure 7.- Continued.



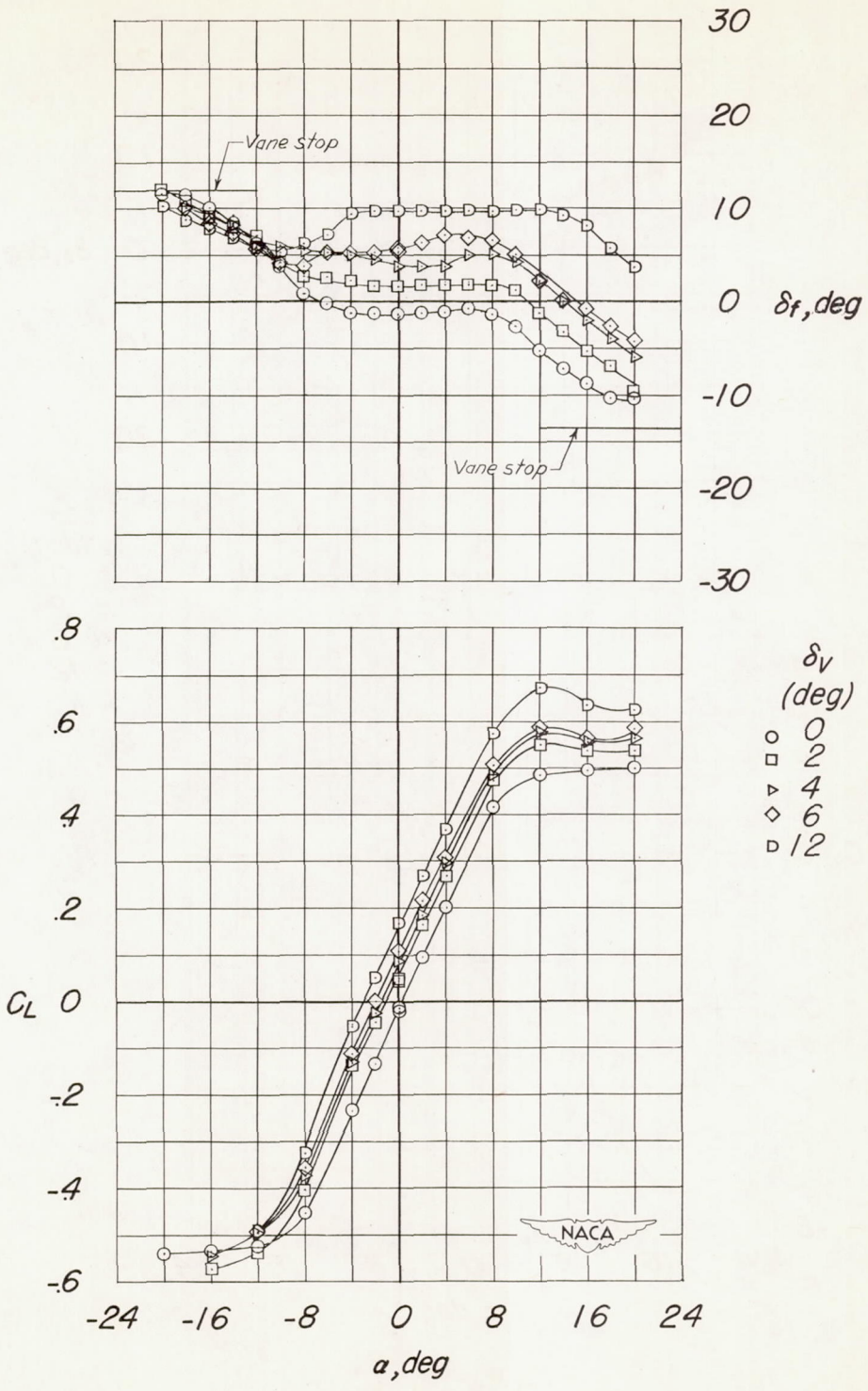
(c) M = 0.80.

Figure 7.- Continued.



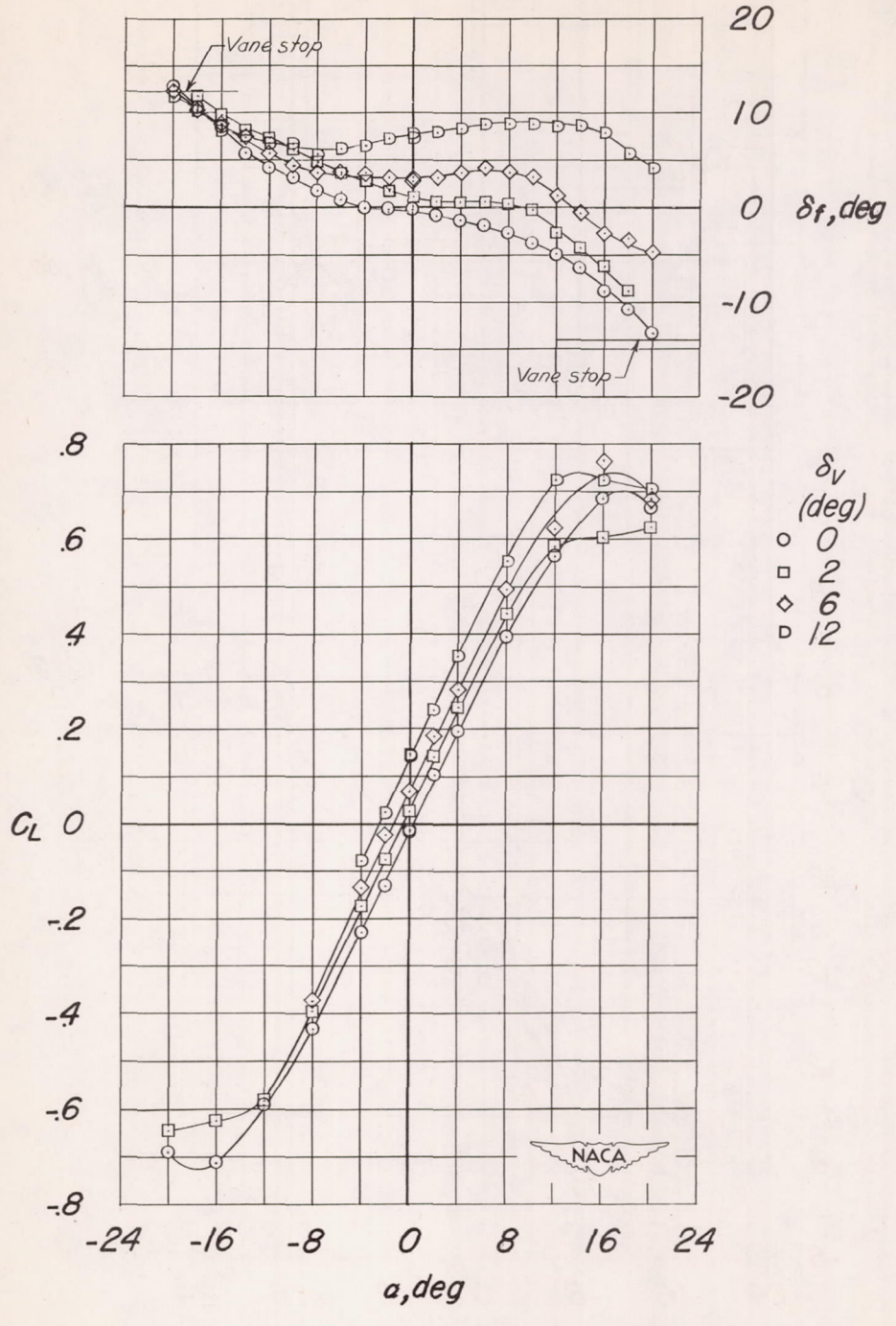
(d) M = 0.90.

Figure 7.- Continued.



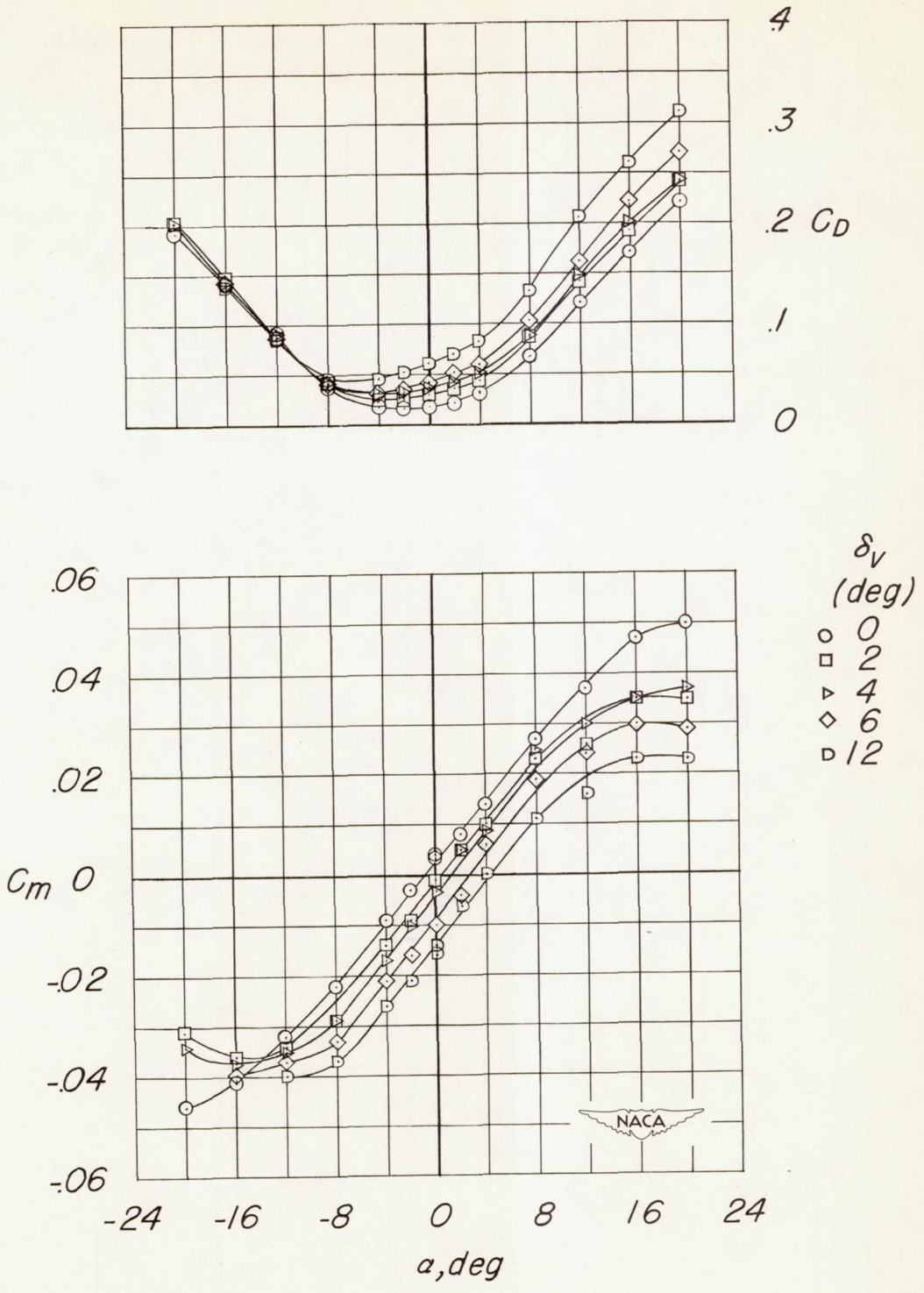
(e) M = 0.95.

Figure 7.- Continued.



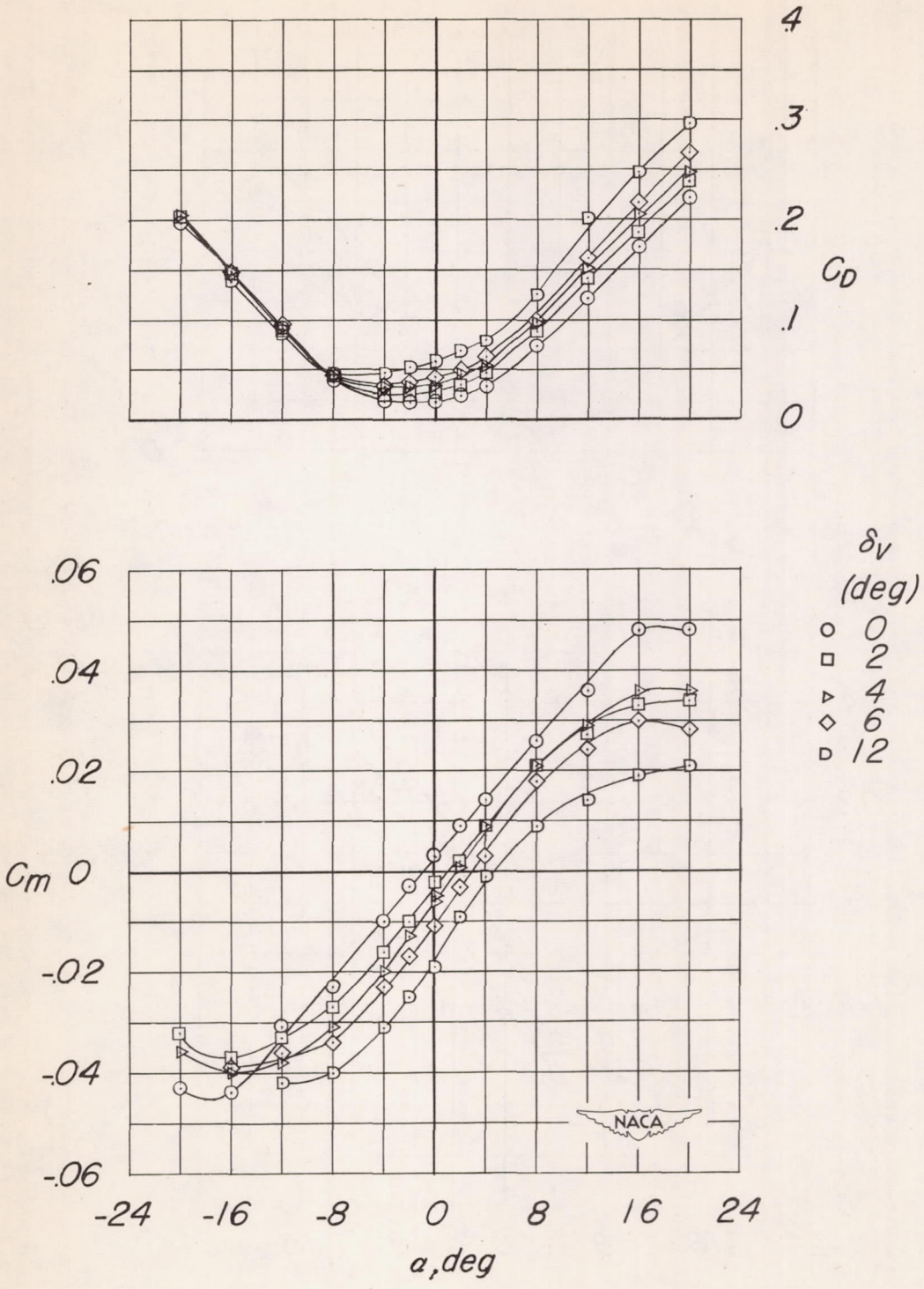
(f) M = 1.00.

Figure 7.- Concluded.



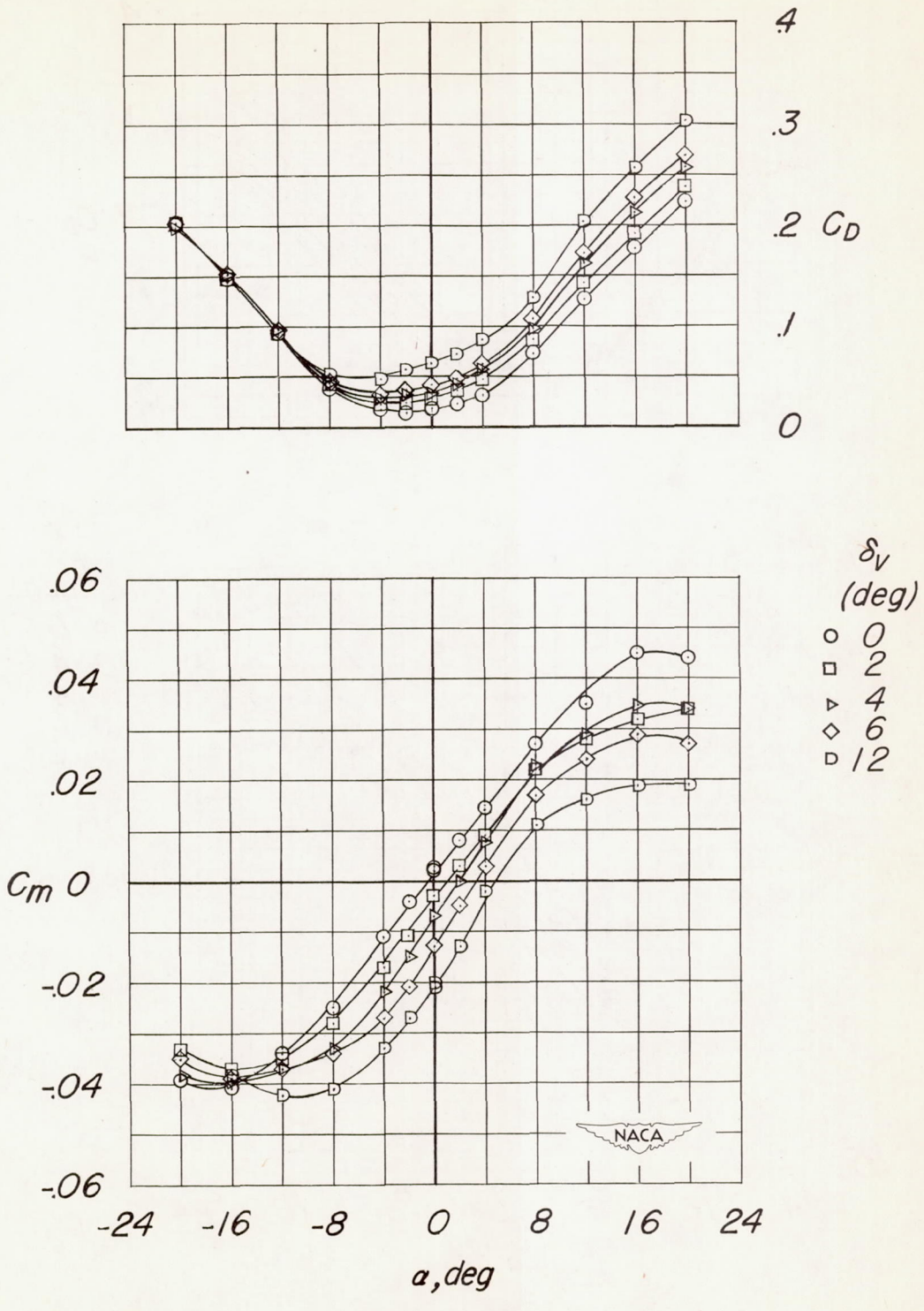
(a) M = 0.60.

Figure 8.- Variation of drag and pitching-moment coefficient with angle of attack for various vane angles.



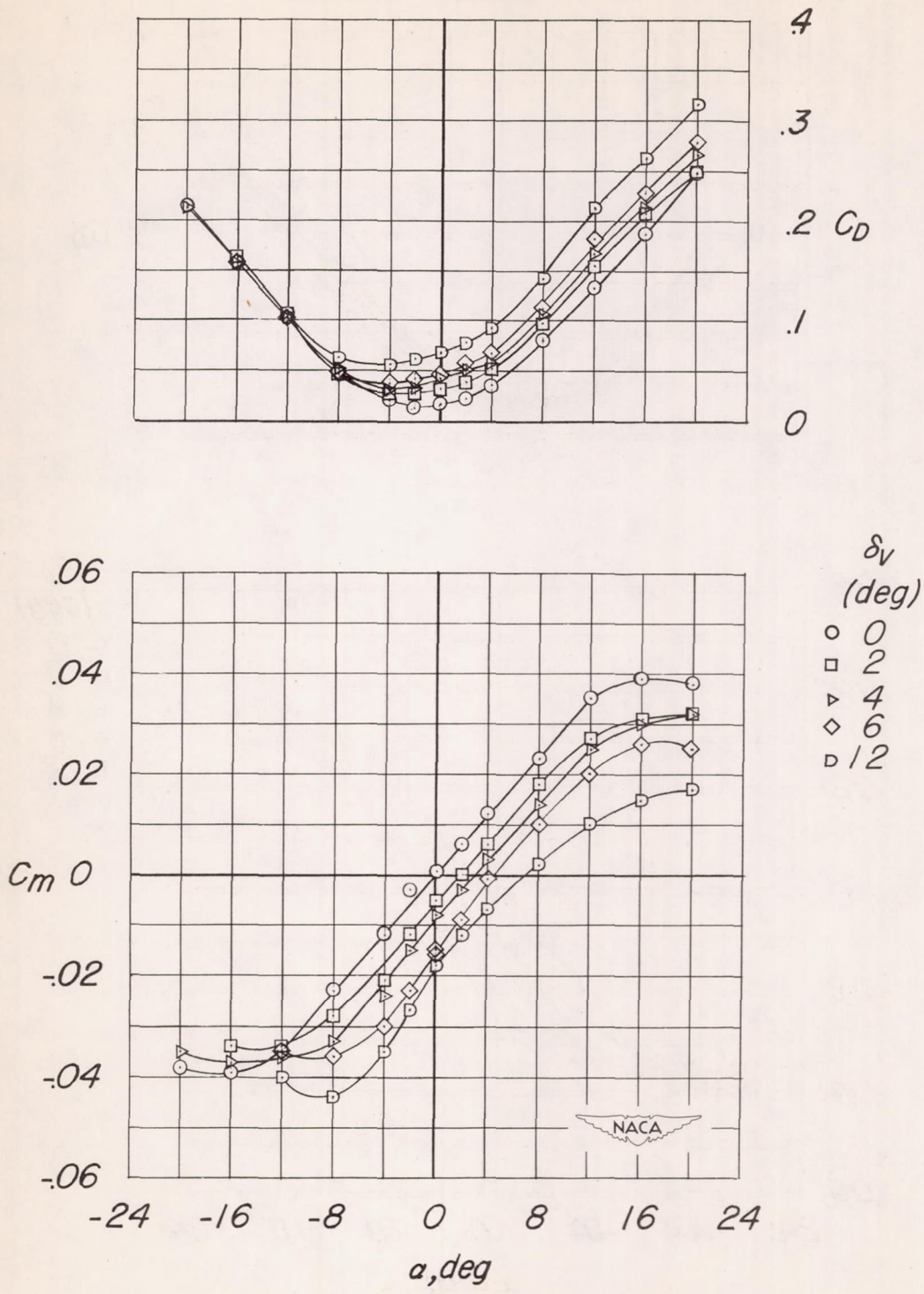
(b) M = 0.70.

Figure 8.- Continued.



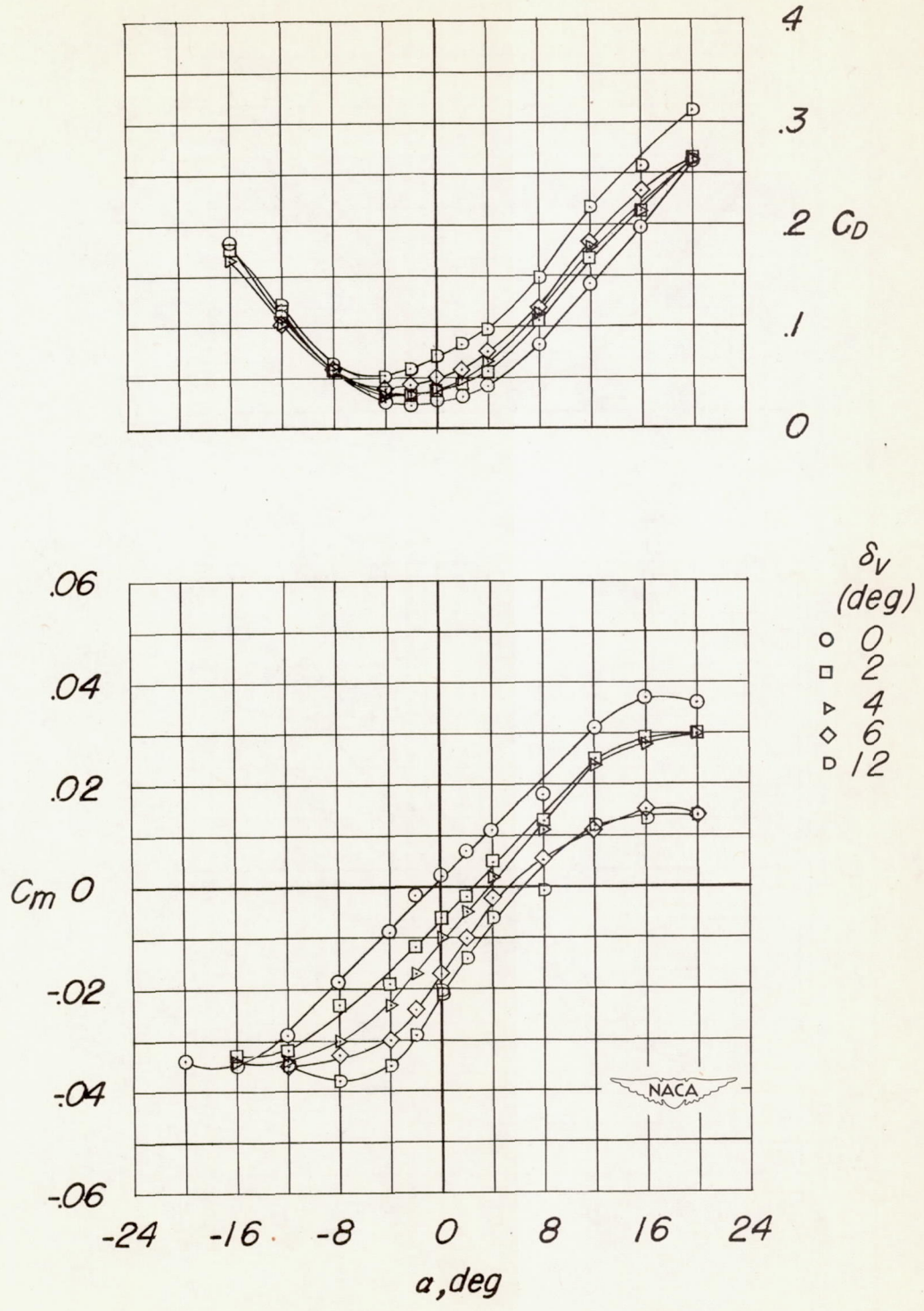
(c) M = 0.80.

Figure 8.- Continued.



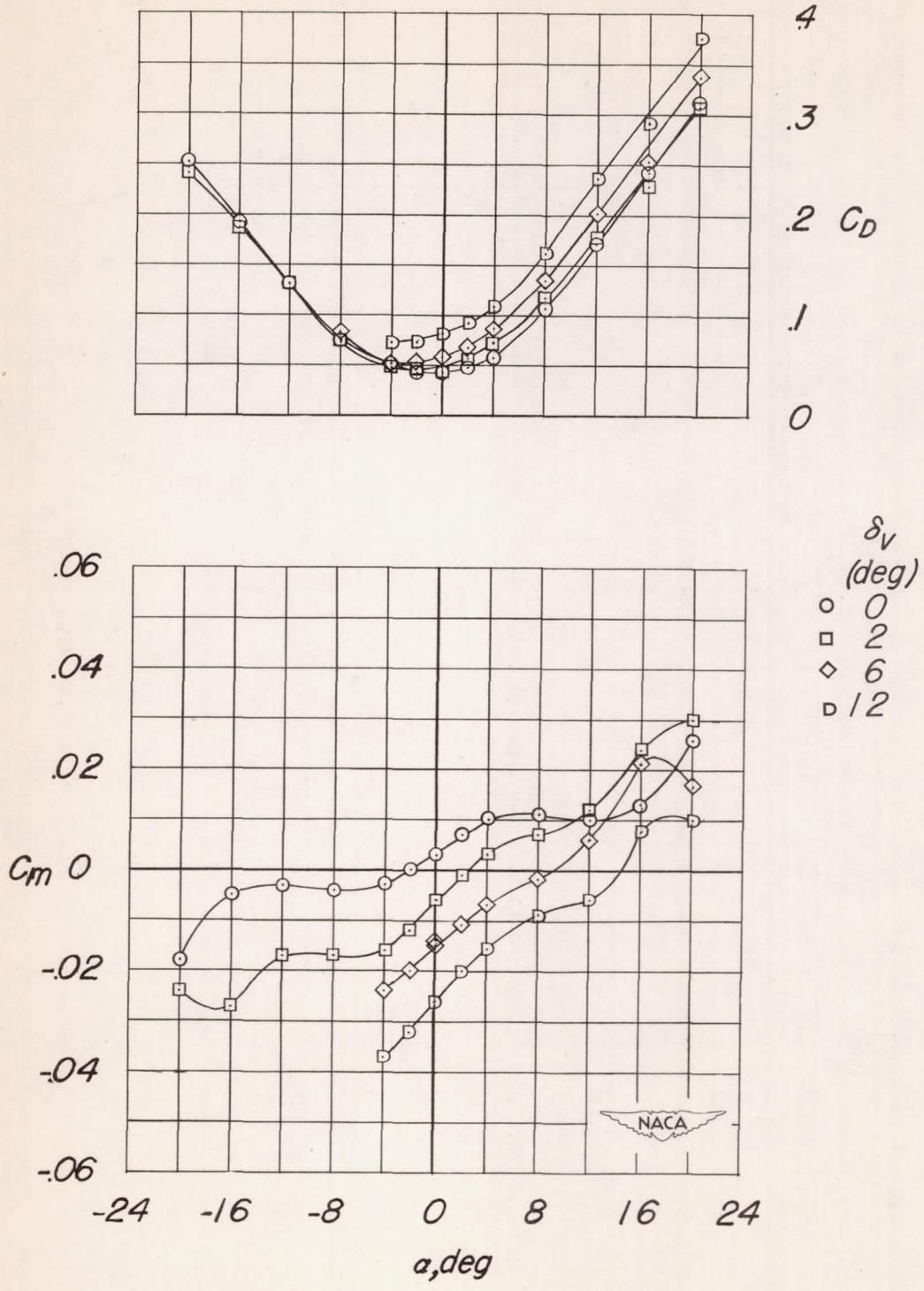
(d) M = 0.90.

Figure 8.- Continued.



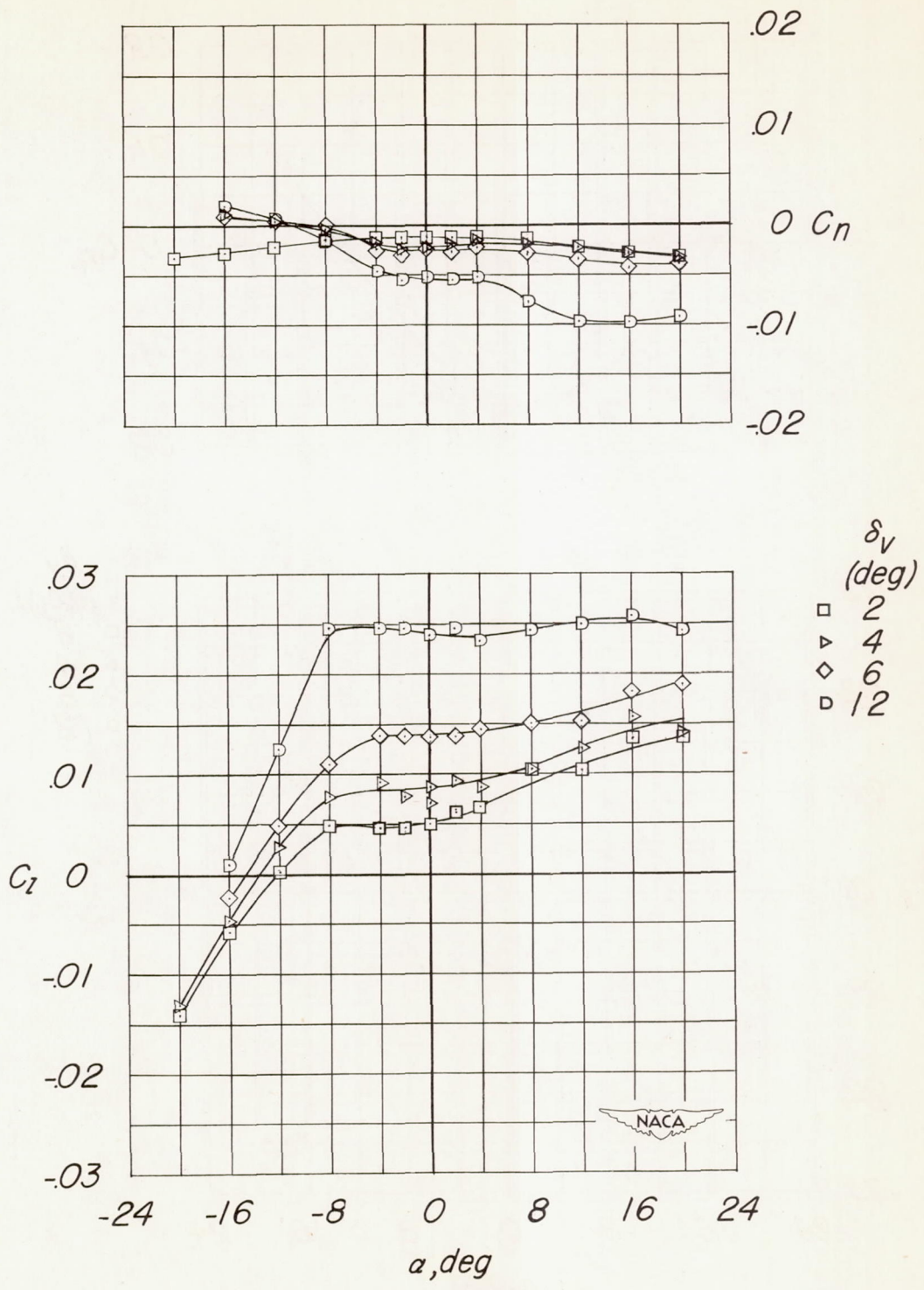
(e) M = 0.95.

Figure 8.- Continued.



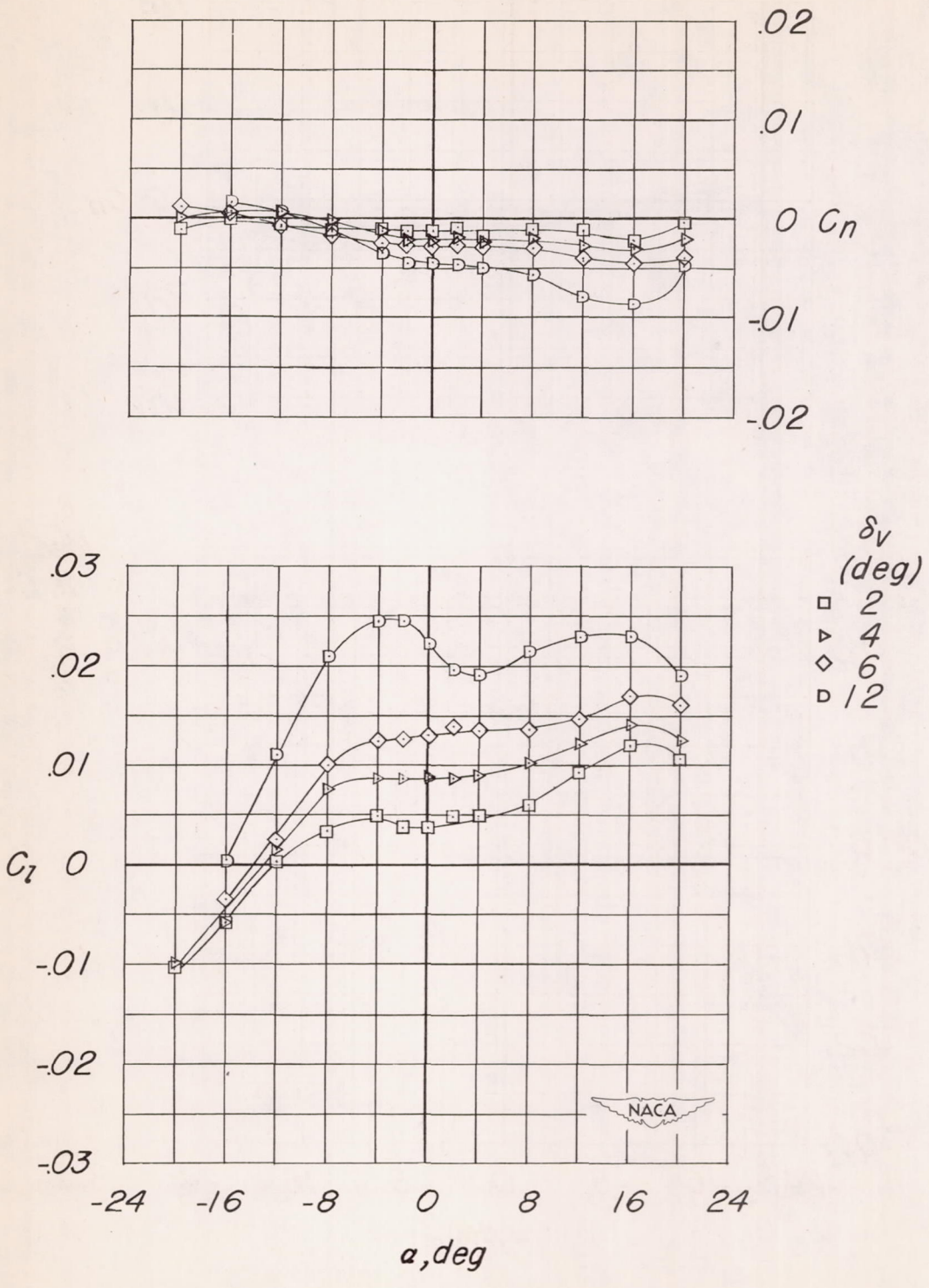
(f) M = 1.00.

Figure 8.- Concluded.



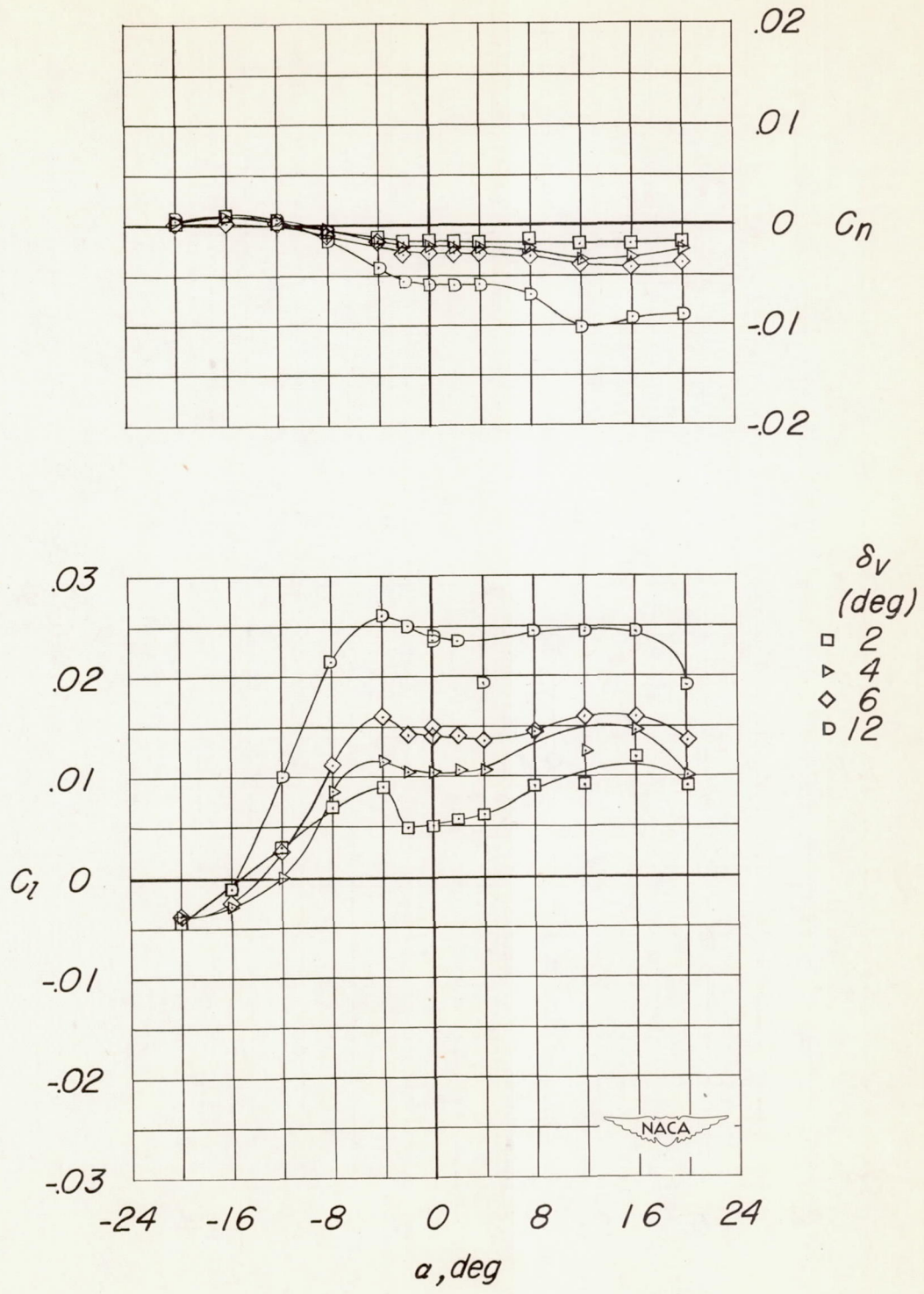
(a) M = 0.60.

Figure 9.- Variation of yawing-moment and rolling-moment coefficient with angle of attack for various vane angles.



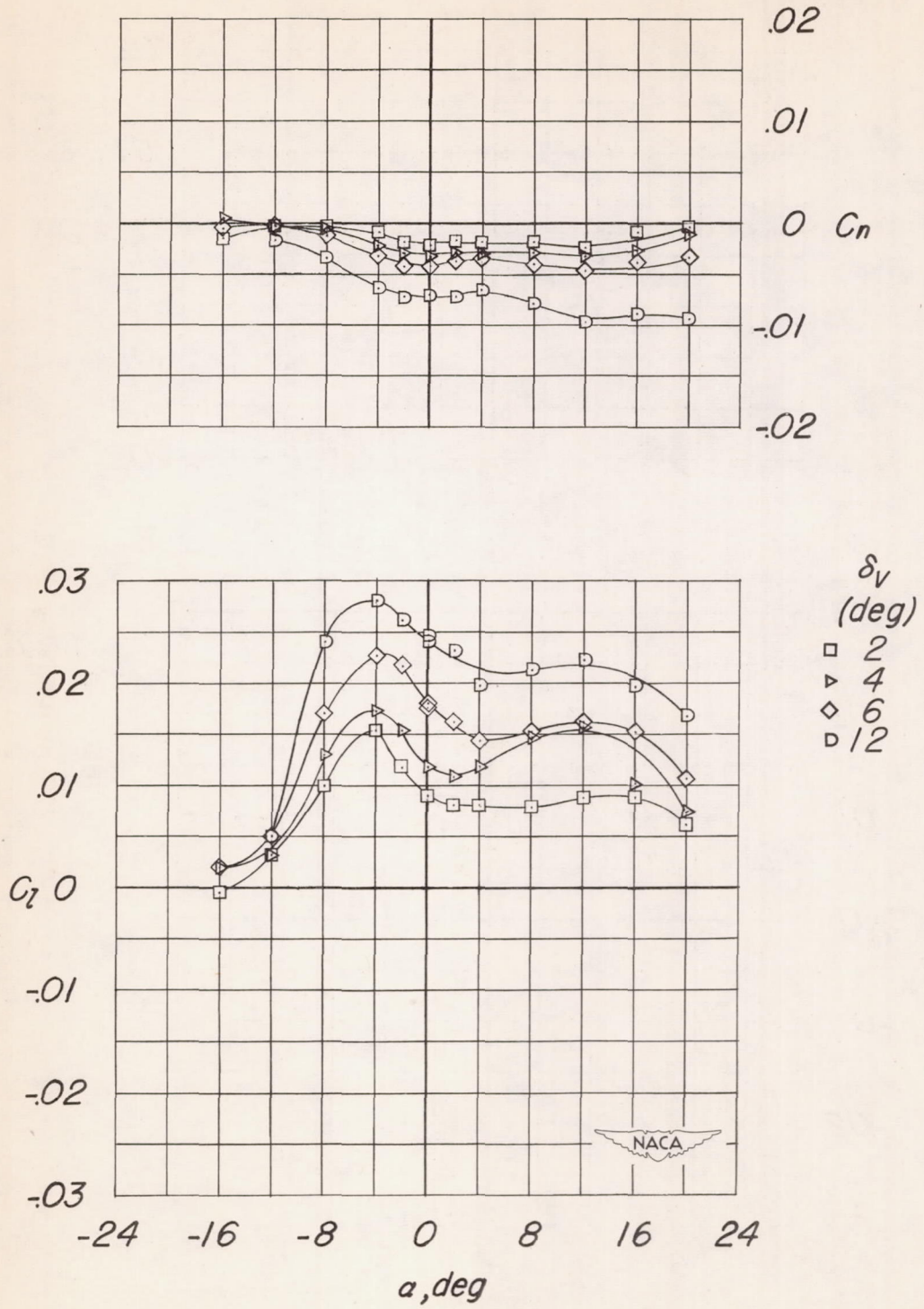
(b) M = 0.70.

Figure 9.- Continued.



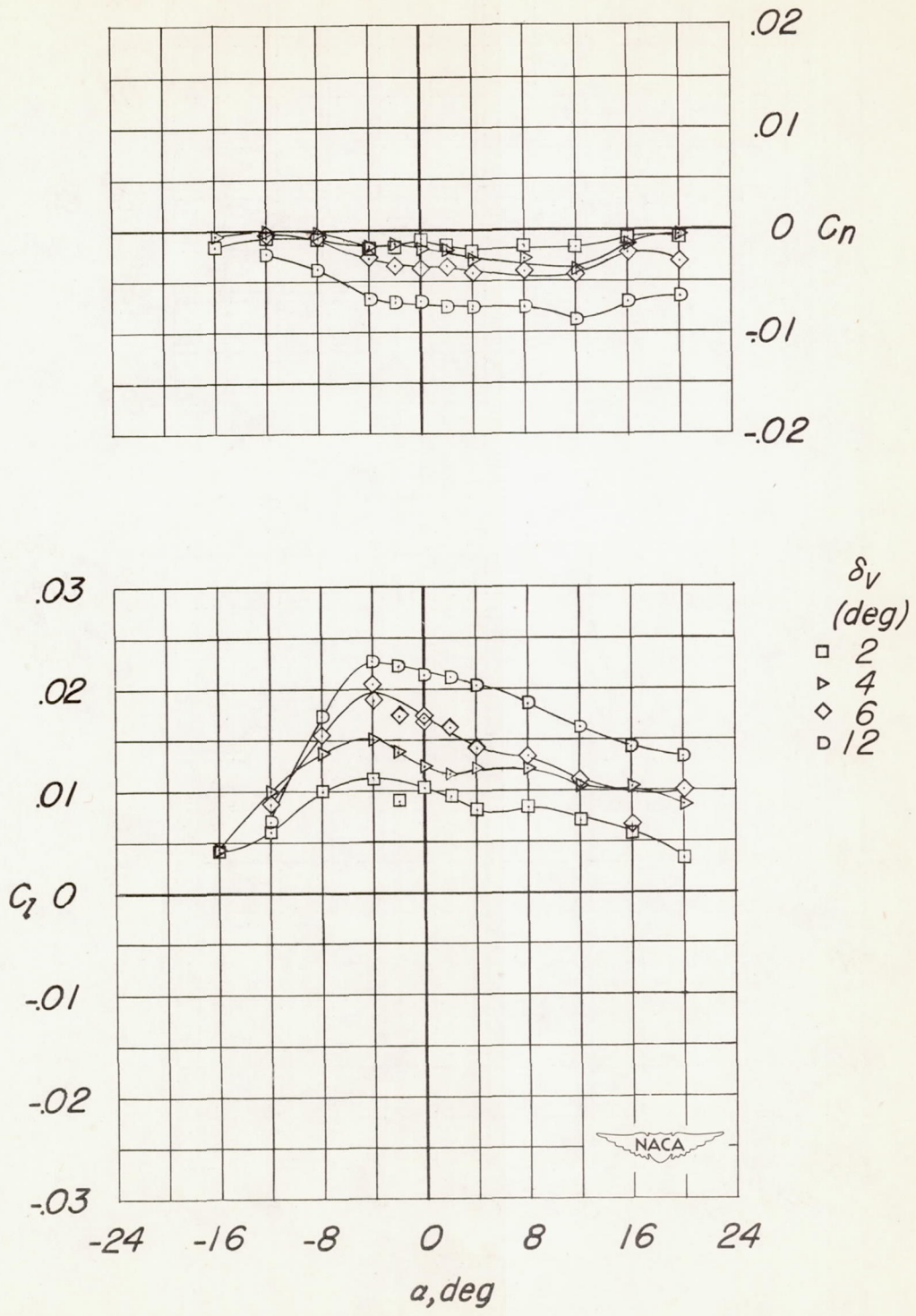
(c) M = 0.80.

Figure 9.- Continued.



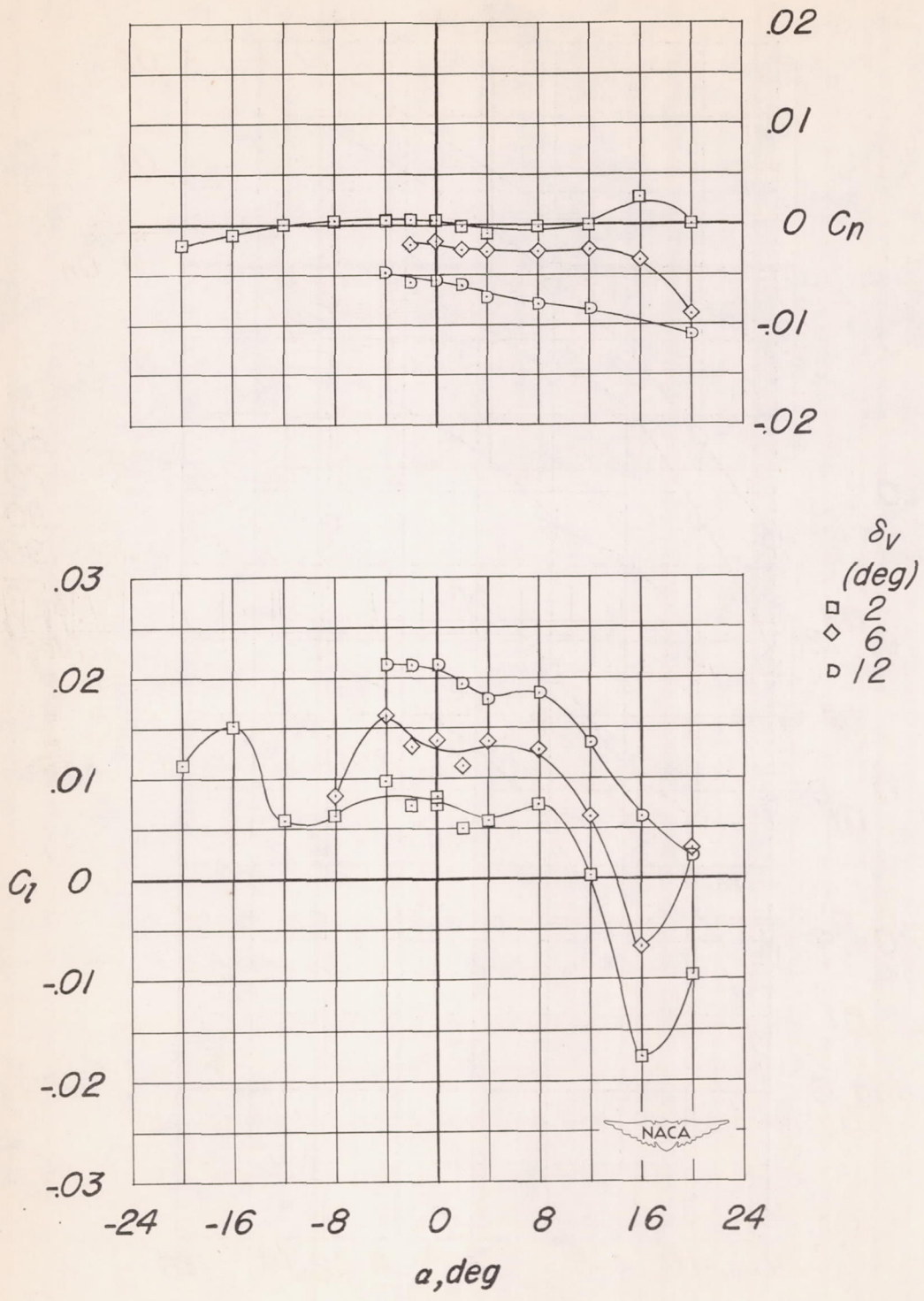
(d) M = 0.90.

Figure 9.- Continued.



(e) M = 0.95.

Figure 9.- Continued.



(f) M = 1.00.

Figure 9.- Concluded.

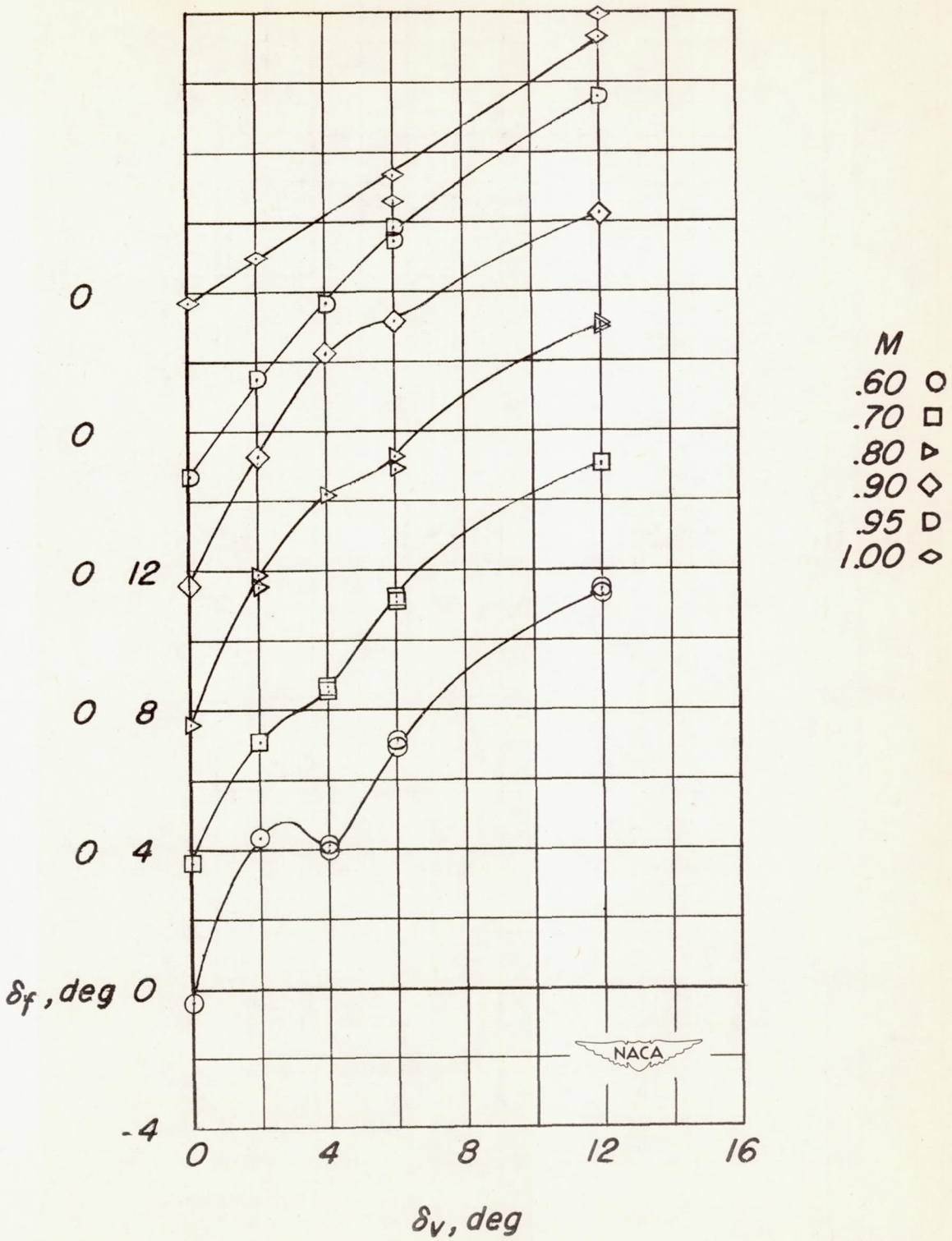


Figure 10.- Variation of flap deflection with vane angle. $\alpha = 0^{\circ}$.

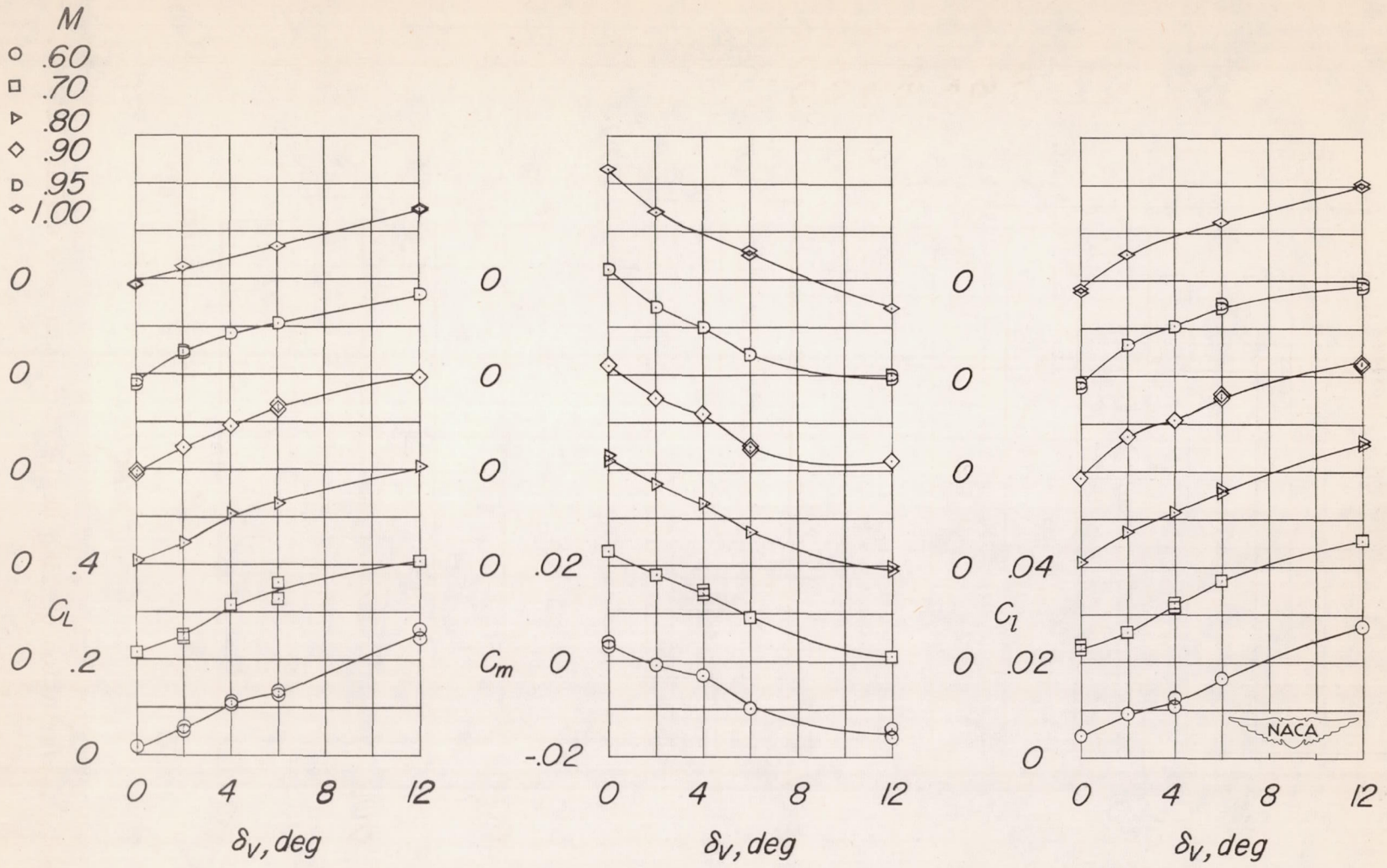


Figure 11.- Variation of lift, pitching-moment, and rolling-moment coefficient with vane angle. $\alpha = 0^\circ$.

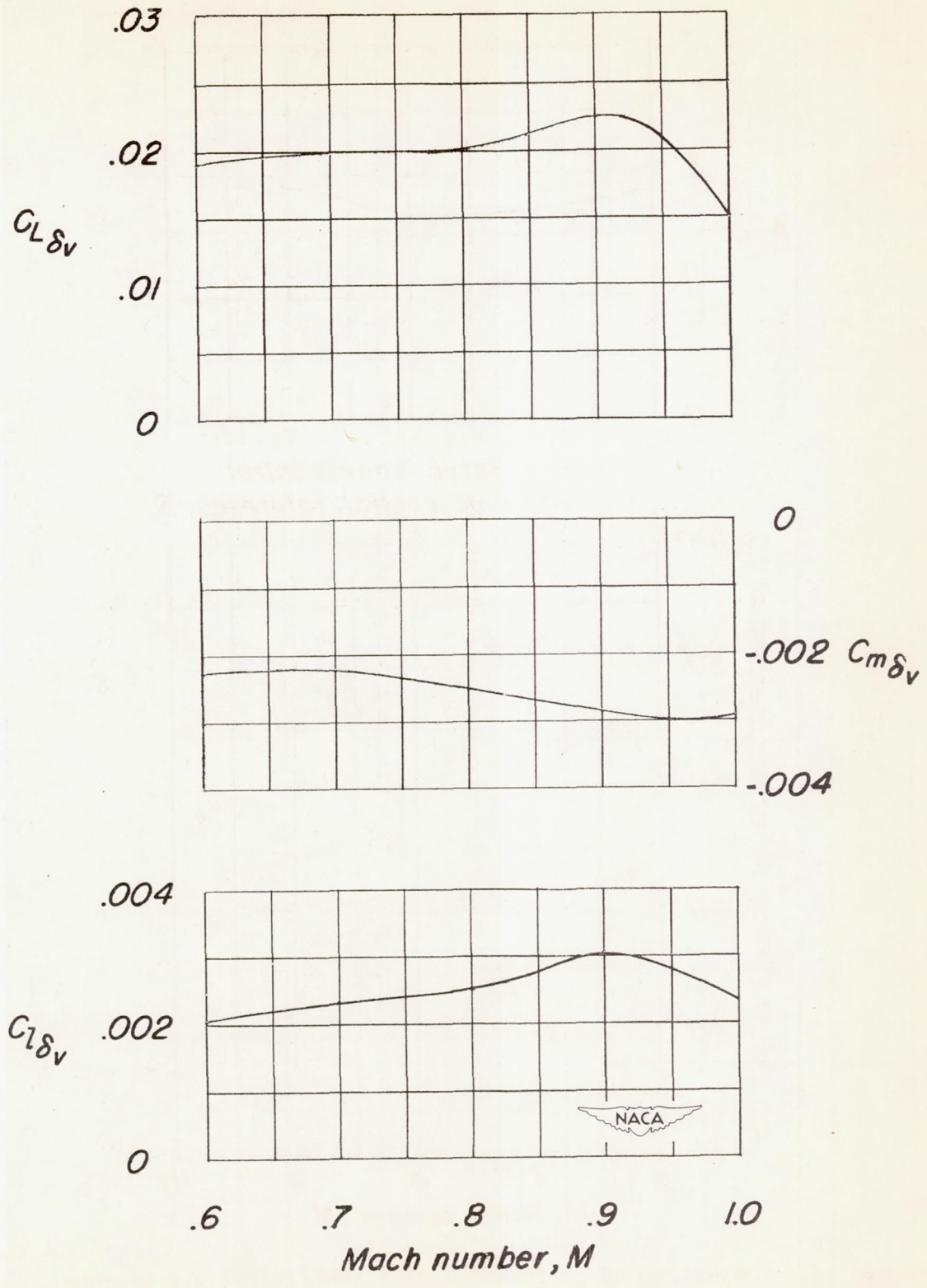


Figure 12.- Effect of Mach number on the aerodynamic effectiveness parameters. $\alpha = 0^\circ$.

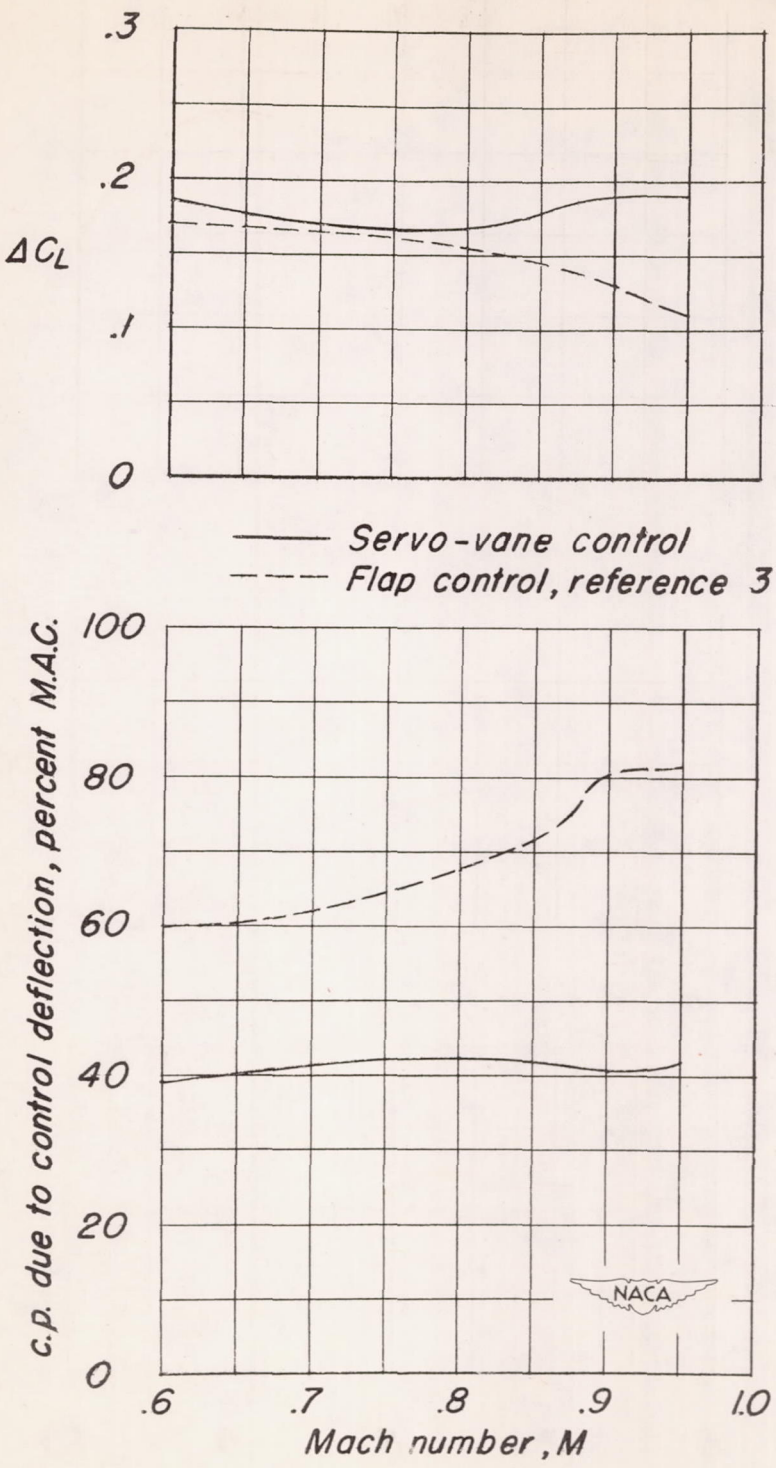


Figure 13.- Comparison of incremental lift coefficient due to vane deflection resulting in 10° flap deflection of the servovane control with the incremental lift coefficient for 10° deflection of a conventional flap-type control. $\alpha = 0^{\circ}$.